SANDS AND CRUSHED ROCKS

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SANDS AND CRUSHED ROCKS

VOLUME I

THEIR NATURE, PROPERTIES AND TREATMENT

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PREFACE

SAND is one of the most abundant substances in the world; its present and possible uses are multitudinous, and far greater than is generally realised, for, notwithstanding their abundance and usefulness, sands have been studied to a very limited extent. Like the clays, which are so complex in structure that few chemists care to study them, and consist of such small particles that geologists and mineralogists can only investigate their properties with the greatest difficulty, sands have largely been neglected by the Universities, and most users of sands have had neither the facilities nor the training to investigate them as fully as is desirable. This neglect, until comparatively recent years, of the systematic study of sands and other detrital sediments is the more unfortunate as many of them are of great commercial importance. It is now being increasingly realised that this branch of natural science presents a very wide field which, if developed, will prove of untold value to the many industries connected with such materials.

Special mention should, however, be made of Professor P. G. H. Boswell's Memoirs on *Sands suitable for Glass-making* (Longmans, Green & Co.), and *Refractory Sands for Furnace and Foundry Purposes* (Taylor & Francis), which are excellent examples of the valuable work in applied science which can be done by an able investigator acting under the auspices of a Government Department in connection with a subject of this nature.

These and numerous papers by other investigators naturally cover only certain aspects of the subject, and, as there is no book in the English language which deals with the subject of sands and crushed siliceous rocks in all its aspects, it has, hitherto, been impossible for any owner of sand to ascertain readily for what purposes his material is suitable. Similarly, users of sand and allied materials have not been able, without an excessive amount of labour, to ascertain the most likely sources of material suitable for their requirements, or to consider whether methods of treatment extensively used in other industries may be applied with advantage to sand.

The purpose of the present volumes is to summarise in a convenient form such geological, chemical, and mineralogical information on sands as is likely to prove of value to those engaged in the digging, sale, and many uses of these materials, and special attention has been paid to the properties which are respectively desirable and harmful in sands used in various industries. It is hoped that, by this means, sellers may find suitable and possibly unexpected purchasers, and users may ascertain what to look for and what to avoid when ordering supplies of sand.

As the nature of the many sands cannot be rightly understood unless their geological origin is appreciated, the various modes in which sands have been formed are described somewhat fully.

To facilitate the study of any particular product, and to assist those readers whose interest is confined to certain chapters, a small amount of repetition has been regarded as permissible, and numerous cross-references have been inserted.

In addition to the information gained in his practice as a consultant on various siliceous materials, the author has, for many years, read all the leading British and foreign scientific and technical papers dealing with these subjects, and a considerable amount of information therein has been included in the present volume. All the relative British patent specifications have been examined, and the leading features of those which, in the author's opinion, are of value have been mentioned.

The author has also been greatly assisted by information willingly contributed by some of his clients, and by that obtained from a large number of other sources, which he has acknowledged as far as opportunity permitted. Since the subject covers so wide a field, and information concerning it is contained in so many publications not readily accessible to the readers for whom this volume is written, it has been considered undesirable to give full references, as these would occupy a large amount of space without serving any proportionately useful purpose.

In collecting the information contained in the following pages, the author has had the invaluable assistance of Mr. W. L. Emmerson, who has also read the proofs; Mr. F. Stones has compiled the Index. To both these gentlemen, as well as to other members of his staff who have rendered assistance in other ways, the author is correspondingly grateful.

ALFRED B. SEARLE.

SHEFFIELD.

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CHAPTER I

THE ORIGIN AND FORMATION OF SANDS

SAND is a term commonly used to indicate a material consisting of small grains of silica, in the form of quartz or quartzite, or of other minerals of a highly siliceous character, though some sands (such as those found in mineral placers) may contain very little of these constituents. It is also applied occasionally to other materials consisting of small irregular particles and possessing an appearance somewhat similar to sand. Thus, when firebricks are reduced to a moderately coarse powder the product is sometimes known as "brick-sand," and carborundum when similarly reduced to powder is sold as "fire-sand." In this volume, the term "sand" is used to indicate any loose, detrital, granular material occurring in accumulations of various kinds as a result of atmospheric, aqueous, chemical, volcanic, or organic action, and of any size between 0·01 mm. and 2 mm. (0·0004 in.-0·08 in.) diameter, but a few other substances in the form of granular powders are included, as they are commonly known as "sands."

No precise limits can be stated for the size of particles of sand, and though the ones just mentioned are usually adopted, there must, of necessity, be some amount of liberty, as some materials known as sands contain particles less than 0·01 mm., whilst others contain particles larger than 2 mm. in diameter. This is particularly the case when the term "sand" is also applied to the materials obtained by crushing sandstones and other rocks or to those obtained as by-products in various industrial processes.

The following definitions proposed by Seger are generally accepted as a "standard":[1]

Silt.—All grains between 0·01 mm. and 0·025 mm. in diameter, washed out by a stream of water having a velocity of 0·7 mm. per second.

Dust Sand.—All grains from 0·025 to 0·04 mm. diameter which are washed out by a stream having a velocity of 1·5 mm. per second.

Fine Sand.—All grains between 0·04 mm. and 0·33 mm. in diameter.

Coarse Sand.—All particles with a diameter above 0·33 mm. but less than 2 mm.

[1] The definitions given by other investigators will be found in Chapter V.

Particles smaller than 0·01 mm. in diameter are usually termed *clay*, whilst particles larger than 2 mm. in diameter are classified as *gravel*, the latter name being applied to particles up to 10 mm. in diameter; for still larger pieces the terms *pebbles* or *stones* are generally used.

It will be observed that the use of the term sand is largely based on the physical properties, and particularly on the size of the grains, rather than on the chemical composition of the material. This distinction is important and should be borne in mind, as it explains why materials of widely different composition and differing from each other in many other respects are all regarded as sands.

THE FORMATION OF SANDS

Sands are produced by the disintegration of various rocks by such natural forces as wind and water, heat and cold, etc. They may be derived from almost all kinds of rocks, though they usually originate from highly siliceous ones. As the nature of a sand depends to a large extent on that of the rocks from which it has been formed, it is important to consider these briefly.

IGNEOUS ROCKS FROM WHICH SANDS ARE DERIVED

Modern geologists are now agreed that all rocks have originally been in a molten condition, though it is improbable that any accessible portion of the earth now remains in its original condition, owing to the action of the weather and to movements in the earth itself.

Rocks whose nature shows that they have passed through a molten state, and have afterwards become solidified, are known as igneous rocks; they form the primary material from which all sands, clays, shales, and many secondary rocks are produced. After being exposed to the weather, and to various chemical and mechanical agencies, they are converted into secondary or sedimentary rocks, in a manner which is described in greater detail later.

The primary igneous rocks appear to have been thrown out from the interior of the earth by violent volcanic action, or they have been injected (by pressure from below) into cracks and fissures in the earth's crust, and in solidifying have formed dykes and veins. Although all igneous rocks are originally the result of internal pressure, and so are, in a broad sense, due to volcanic action, it is customary to divide them into three groups, the term "volcanic" being limited to those materials which have been thrown on to the surface of the earth in geologically recent times. In this way igneous rocks may be classified as (i.) Plutonic rocks, (ii.) Hypabyssal rocks, and (iii.) Volcanic rocks. Each of these

divisions is further classified according to their chemical composition as shown in Table I.

TABLE I.—CLASSIFICATION OF IGNEOUS ROCKS

Origin . .	Plutonic.	Intrusive.	Volcanic.	Volcanic.	Chief Constituents.
Nature . .	Holo-crystalline.	Hemi-crystalline.	Semi-glassy.	Glassy.	
1. Acid . .	Granite	Quartz felsite, elvans	Rhyolite	Obsidian	Quartz, felspar (orthoclase), micas (muscovite, biotite).
2. Sub-acid .	Syenite	Minettes	Trachytes	Pitchstone	[illegible]
3. Sub-basic.	Diorite	Kersantite	Andesite	..	
4. Basic .	Gabbro	Dolerite	Basalt	Tachylite	[illegible]
5. Ultra-basic	Peridotite	Picrite	Limburgite	..	[illegible] or hornblende.

PLUTONIC ROCKS

Plutonic rocks consist largely of aggregates of a coarsely crystalline character, the distinctive features of each variety depending on the predominance of some one or more particular constituents.

Granitic rocks are widely distributed, and form the principal mass of the chief mountain ranges, especially those in Northumberland, Cumberland, Westmorland, Devon, and Cornwall, in England, the Grampians in Scotland, and in Antrim and Wicklow in Ireland. They are mixtures of various siliceous minerals cemented together into a hard and compact mass, the chief constituents being felspar, quartz, and mica, though leucite, nepheline, free silica in various forms, and small quantities of various other silicates may also be present.

Felspar is generally the principal constituent, quartz being next in importance, and mica third. The quartz often surrounds and encloses less stable and less durable minerals, thus acting as a protecting agent. As all the most important constituents of granite are siliceous, the proportion of silica is very high, being usually over 66 and sometimes as much as 80 per cent. The specific gravity is about 2·65.

Being the oldest of the accessible rocks, the granites are usually found beneath the others, but in many instances they have been thrown upwards by earth movements or uncovered by weathering, so that they also form prominent mountains and hills. Granitic rocks also form dykes and veins in sedimentary rocks of much later formation, or even in other granitic rocks. The material forming these veins and dykes is often somewhat different mineralogically from the main granitic mass from which it is apparently derived, and it often contains minerals not found in the latter, such as

beryl, garnet, and other precious stones. Granite rocks may, in fact, occur in any formation and may be produced at any time.

The accessory minerals found in granite are sometimes in sufficient quantity to make them important, and many types of granite are named after the particular accessory mineral which predominates. Thus, *tourmaline granite* contains tourmaline in place of some of the mica, *hornblende granite* contains a considerable proportion of hornblende. These accessory minerals give characteristic colours to the granite in which they occur, and consequently granitic rocks from different parts of the country vary considerably in colour. Thus, granite from Devonshire and Cornwall is chiefly grey in colour, with a well-compacted grain, in which hornblende is very noticeable. Nearer Land's End, yellow porphyritic granite is found containing large characteristic crystals of felspar known as "horse's teeth"; whilst Shap granite of Westmorland contains large red felspar crystals, and takes a beautiful polish. Scotch granites are usually bluish grey, and so is much of that in Ireland, though red granite is found in Galway and Donegal.

As granites are really heterogeneous mixtures of certain minerals, they have no definite chemical composition, and in the same hill half-a-dozen varieties may often be found, the differences being due to variations in the compositions and the proportions of the various felspars and mica present in addition to the quartz and accessory minerals.

Syenites are an intermediate variety of plutonic rocks, consisting chiefly of felspar (pink orthoclase with some plagioclase) and hornblende, quartz being present in a much smaller quantity and only as an accessory mineral. They form a group of rocks of varying composition, and bearing different names according to the predominant constituents. Zircon occurs occasionally in important amounts.

Diorites are also intermediate rocks, and resemble grey granites in outward appearance. They consist principally of plagioclase-felspar and hornblende, together with accessory augite. Quartz is sometimes present and may be an important constituent in acid diorites.

Gabbros are more basic than syenites and diorites, and consist of a plagioclase-felspar together with pyroxene minerals, containing high percentages of iron, lime, and magnesia, from which they derive the name of basic rocks. The particular variety of ferromagnesian mineral present varies in different rocks; accessory quartz also may be present.

Hypabyssal Rocks

Hypabyssal rocks are intermediate in structure between plutonic and volcanic rocks. Generally they are fine-grained, but the basic varieties are coarser. They are sometimes termed "trap-rocks," on account of the fact that they usually occur as dykes and igneous

intrusions in other rocks. They are widely distributed, forming large portions of the Cheviot, Welsh, and Derbyshire Hills, and occur less extensively in Leicestershire, South Devonshire, and Cornwall, the Pentland and Lammermuir ranges in Scotland, and the bulk of the Irish hills; in short, the chief districts occupied by the " Old Red Sandstone " and the " Coal Measures."

They are often columnar in form (cf. Giant's Causeway), and are undoubtedly of igneous origin, but some having been formed at great depths, some under the pressure of water, and others having been re-fused and passed through more than one eruption, their texture and character are naturally extremely varied, especially as some of them have been cooled more rapidly than others.

Trap-rocks may be named, according to the predominating mineral, as augitic, felspathic, hornblendic, etc., or porphyritic when they are composed of the isolated crystals set in a crystalline magma. They are termed " tuffs " when soft and porous. Some soft earthy varieties are termed " wacke."

The principal minerals in trap-rocks are dark in colour (hornblende being a black or dark green and augite black or dark brown), and their decomposition products are usually dark in colour, and are very different from the white or almost white clays and sands obtained from the Cornwall and Devon granites. The colour is largely attributed to the presence of ferrous oxide, which partially replaces magnesia in hornblende and augite, and contaminates the products formed by their disintegration.

The principal varieties of hypabyssal rocks correspond to the plutonic rocks and are largely porphyritic in character.

Porphyry is a term given to a large number of rocks consisting chiefly of a crystalline mass, in which larger individual crystals are clearly visible, as granite containing porphyritic crystals of felspar, or a felspar containing similar crystals of another felspar. Porphyries are formed when a fused mass containing more of one mineral than is required to form a eutectic is cooled; the substance in excess forms the larger crystals, the magma being the eutectic, or substance of minimum melting point. The term porphyry is not by any means confined to felspathic minerals, though most porphyries are felspathic. It was originally confined to a definite red felspar found in Upper Egypt, but is now used to indicate so many minerals that it is better to consider it as indicating a definite physical structure or texture than as representing a single mineral.

The principal hypabyssal porphyries are:

Quartz-porphyry, felsite, or elvans corresponding to the granite series and consisting of quartz crystals embedded in a microcrystalline mass of orthoclase-felspar. It is sometimes termed micro-granite on account of its resemblance to granite. Quartz-porphyries exist chiefly as intrusions or dykes in the overlying beds, but the term is also used in Cornwall for fine-grained granites.

Syenite-porphyry consists of fine-grained felspar, forming the

ground-mass and containing isolated crystals of biotite and hornblende.

Diorite-porphyry consists of a fine ground-mass containing crystals of plagioclase-felspar, biotite, and hornblende, quartz also being present in some cases, either as an accessory or as a cement.

Dolerite is a coarsely crystalline variety of basalt which is early decomposed by saline solutions and by the action of the weather.

Felstone or **Claystone** is composed essentially of amorphous felspar, but becomes felstone-porphyry when crystalline masses of felspar are found in it.

Volcanic Rocks

Volcanic rocks to some extent overlap the previous section, but may be taken generally to include recent volcanic accumulations as lavas which, when cooled, form various trachytes, basalts, and tuffs of all kinds from glassy obsidian to a soft earthy material, and in pieces of all sizes from large masses to the finest dust. This dust, when moist, often forms a kind of hydraulic cement, which binds scoriae, small stones, and sand into conglomerates, breccias, etc. Alone, it forms pozzuolana and trass.

The following are the principal varieties of volcanic rocks :

Rhyolite is a crypto-crystalline to glassy rock of similar chemical composition to granite; it sometimes contains quartz crystals and clear felspar.

Trachytes are equivalent to the syenites, the ground-mass being felspathic and containing isolated crystals of felspar, hornblende, biotite, or augite.

Phonolite or **Clinkstone** are easily decomposable rocks having a ground-mass of sanidine and nepheline in which occur crystals of orthoclase-felspar, nepheline, and pyroxene. Leucite may also be present.

Andesite is a porphyritic rock having a felspathic ground-mass and including crystals of labradorite or andesine, together with biotite, hornblende, and augite.

Dacite contains quartz in addition to other constituents.

Basalt is a dark brown rock consisting chiefly of plagioclase-felspar and augite, together with magnetite and olivine.

Variolite and **Tachylite** are basaltic glasses.

The **Pitchstones** are closely related to felstone, but have a vitreous lustre resembling pitch when broken.

From the above it will be seen that the original igneous rocks from which others are derived consist of aggregations of crystals more or less cemented together to form compact rocks. The rocks are disintegrated under the influence of different natural agencies, forming detrital sediments of various kinds.

The character of the sediments produced will depend on: (*a*) the nature of the original rock, (*b*) its chemical composition, (*c*) the ease with which it can be disintegrated, and (*d*) the agencies

to which it is subjected. Thus, the sand derived from a rock containing a large proportion of felspar will tend to be felspathic, whilst that from a rock consisting of almost pure quartz will be a very pure silica sand. The more detailed consideration of the nature and chemical composition of the minerals composing the original rocks will be found in Chapter IV.

FORMATION OF PRIMARY SANDS FROM IGNEOUS ROCKS

The agencies responsible for changes in rocks may be divided into two classes :

(*a*) *Hypogenic actions*, which are the result of heat or chemical activity, and are closely connected with earthquakes and volcanoes. Where they occur, minerals tend to become consolidated or even crystalline and to form new minerals. These changes are sometimes known as *metamorphoses*. When air or other gases, and superheated steam or other forms of water vapour, take part in these changes they are known as *pneumohydrogenic* ; or if air and other gases without water form the chief chemical agent, the action is said to be of a *pneumatolytic* nature. The chemical and other changes involved are so numerous and so complex that no single term for the whole of them can be completely satisfactory, though Sir Charles Lyell's term " hypogenic " (meaning " formed under the surface ") is convenient, as distinguishing all those changes which are of an internal and not of a superficial nature.

(*b*) *Epigenic* or *surface actions* are produced by the circulation of air and water, and to some extent by the alternation of heat and cold. Epigenic actions may conveniently be summarised under the term " weathering."

Hypogenic actions are largely of a constructive nature forming new compounds, so that they only play a limited part in the production of sands, whilst epigenic actions, being in the main destructive, effect more directly the formation of sands. Thus, hypogenic actions appear to play the chief part in the production of some clays, but epigenic actions are usually, though not always, the chief producers of sands.

The formation of primary sands may be stated briefly as consisting chiefly in the destruction of primary rocks by epigenic action, aided to some extent by hypogenic action. The loose aggregation of minerals, produced by the destruction of the bond in the compact rocks, is further acted upon by various natural agencies to form beds or deposits. When these beds or deposits are subjected to further weathering, secondary sands are produced from the primary ones. In such cases, one class of minerals is generally concentrated in one bed of sand, whilst another class of minerals will form the bulk of another bed, which may be at some distance from the primary sand deposits.

Hypogenic actions are chiefly of value in the formation of sands ıen they cause such changes in the chemical composition of the ırious minerals composing the rock as to render them more easily disintegrated by epigenic action, or when they cause splitting, cracking, or other physical disturbances in the primary rocks and so tend to render the latter less resistant to epigenic action. Such changes have occurred chiefly during the cooling of the igneous rocks after their discharge from the interior of the earth. Within the interior of the earth itself the materials cool so slowly that large crystals of felspar and other minerals can form, and probably float about in, a pasty liquid made up of fused minerals. When, however, a mass of this pasty liquid is discharged by extrusion or volcanic action, the liquid portion cools relatively quickly, with the result that crystalline matrices are formed, or—as in many cases—a natural glass is produced. The coarser portion is known as the " plutonic " or slowly cooled phase, and the much finer crystalline or glassy magma is the " volcanic " or rapidly cooled phase of the same material. In this way, the physical conditions of the minerals at the time of their discharge determines, to a large extent, whether they form granitic, hypabyssal, or volcanic rocks. The first named appear, to a large extent, to have been intruded into the overlying rocks in a pasty or almost solid condition. The hypabyssal rocks, on the contrary, appear to have been poured out in a semi-liquid form as lava, and to have cooled more quickly, whilst the lava from more recent volcanic action is still, in some cases, undergoing the rearrangement of its constituents, which is included in the term hypogenic action.

The ever-changing internal pressure of various parts of the earth's crust brings about important modifications in the nature and characteristics of the rocks affected by it. Sudden upheavals or depressions of the ground may occur, and may result in serious changes in the physical character of the neighbouring rocks. Volcanic action may cover a rocky mass with lava, and the heat from this may cause a further change in the character of the rock itself, and the effect of enormous pressure (caused by large masses of other rocks being piled up on a particular bed of material) is usually to consolidate a material so much as to change it from a bulky, amorphous substance into a mass of compact crystals. In this way, many rocks have changed their character completely. The chemical action of various vapours and of substances in solution is also responsible for many changes in the composition of rocks. Thus, the action of subterranean vapours of fluorine and boron emanating from the fissures and joints in igneous rocks during the dying phases of pneumatolytic action may cause changes (such as kaolinisation, and the decomposition of various calcium and alkali-silicates, such as felspar, mica, etc.) in such rocks, which will render them more easily disintegrated when subjected at a later date to epigenic actions. More recent investigations by Ussher and others appear, however, to support Vogt's hypothesis

that carbonic acid was the principal, though probably not the only, gas involved in such changes.

The action of water containing other dissolved substances, when circulating through igneous rocks at great depths, may also play a considerable part in the decomposition of these rocks, especially as the experiments of Bogojwlenski and Tamman have indicated that under a sufficiently high pressure all acids and bases are equally active. Moreover, J. M. Coon has pointed out that three well-known series of joints or fissures in the granite formation in the Hensbarrow district, in Cornwall, are so situated that the intertelluric water will be in constant alternation according as the seasons are wet or dry; and in flowing from one boss of granite to another, much of the water will descend to great depths, and will become heated and charged with such substances as are soluble under these conditions. Such water rising upwards and again infiltrating through the granite mass will tend to decompose it, yielding sands and china clay as two of the most important products.

Epigenic actions comprise all those changes in the composition and distribution of minerals which are brought about by the action of air, water, and ice in conjunction with climatic conditions, and which are known as "weathering." Epigenic actions are of three main kinds:

(*a*) *Atmospheric agencies*, including wind, frost, glacial action, chemical decomposition such as oxidation, carbonisation, dehydration, changes in the colloidal state due to heat or drying, etc.

(*b*) *Aqueous action*, including that of rain, sea, tides, currents, streams, rivers, etc.

(*c*) *Organic action*, including that of animals, vegetation, etc.

In these, mechanical and chemical influences unite and operate in a highly complex manner.

Atmospheric Agencies

Air plays a very important part in the disintegration of rocks. Its action is partly mechanical and partly chemical. When dry it has little chemical influence, unless the rocky material is rather moist, when oxidation often occurs, as in the conversion of greenish or black ferrous compounds into red ferric ones.

Carbon dioxide is contained in air in very small proportion, but the total quantity present is very great. This gas dissolves readily in water and forms carbonic acid, which combines with free bases or very weak salts in the rocks and forms carbonates and bicarbonates. As a solvent of various minerals, its action is best considered in another section.

Rapidly moving air (wind) disintegrates rock, partly by removing the smaller particles and so exposing the remainder to other agencies. Its action is also abrasive, as it blows any loose materials against the rock surface and abrades it. In the form of a gale or

hurricane, air moving at a high speed will often carry large pieces of rock for a considerable distance, and may cause the disintegration of others by the hammering action of the pieces it carries. Strong winds carrying with them inexhaustible supplies of sharp-edged grains form a natural sand-blast whose action is the same as the artificial sand-blast used in many industries (see Vol. II. Chapter XIII.)

Many rocks of peculiar shape have been produced by the abrasive action of wind-borne particles upon their surface. Typical examples of this action are to be seen in many parts of this country, as at the Brimham rocks, Harrogate, the Bride Stones, near Todmorden, and the Bride Stone, near Pickering. The Sphinx owes much of its present outline and polish to the action of a natural sand-blast. The abrasive action of sand and dust carried by the wind against other rocks is one of the most important weathering actions in hot, arid lands, such as deserts.

Temperature changes in the atmosphere have a very important action in disintegrating rocks. The heat of the sun, transmitted through the atmosphere to the rocks, causes those near the surface to expand, particularly in tropical countries, and the contraction which takes place at night (when the temperature may fall over 50° C.) is frequently a powerful factor in the breaking up of such rocks. The daily variations only affect the ground to a small depth, but the seasonal changes have a much greater influence. If water enters into crevices between pieces of rock and freezes, it will expand and so will tend to break the rocks by its pressure; whilst if a rock is at all porous and is saturated with water prior to freezing, the disintegration will be more complete. This action is more noticeable on higher ground, where soil does not gather, and in mountain ranges the cracking of the rocks in winter may frequently be heard. When large masses of rock become detached, an avalanche or landslip is the result, and this mechanically causes a further breaking up of the rocks by the force it exerts in its passage to a lower level.

The action of frost is particularly important in the Arctic regions, and at high altitudes, and in those places forms one of the most potent weathering agencies. The sharp and angular peaks characteristic of high altitudes are due to the shattering action of frost. It should be noted that frost works by disintegration and not by the decomposition of the rock.

The atmosphere also has an oxidising action upon many minerals and aids in the disintegration of rocks. Sulphides (such as pyrites, marcasite, and pyrrhotite) become oxidised, nitrates and carbonates may be formed, and these and other compounds are frequently hydrated, producing haematite, magnetite, and hydrated iron compounds such as limonite, goethite, and turgite. The sulphur in some minerals, when oxidised, forms sulphuric and other acids which also exert a chemical action and form compounds such as the alums and gypsum. Various metals are also affected by

weathering and produce oxides and other compounds of little importance from the point of view of the student of sands.

Snow and **Ice** are the most potent weathering forces in very cold lands and at the highest altitudes. They have a mechanical action in disintegrating rocks which is similar to that exerted by rivers (p. 12). The snow on mountains forms large masses or "fields," and, as the lower portion melts, these masses slide downwards—often with great speed—and the resulting avalanches do serious damage to the rocks over which they pass. All the loose boulders in the path of an avalanche are carried downwards, and if the mass is arrested by a projecting rock, its weight is often so great that, in many cases, the stop is only temporary; the rock eventually gives way and falls with the snow into an adjacent valley.

Still more powerful in its total results is the snow which accumulates in the upper valleys. As its depth increases, the lower layers are compressed into ice and the whole mass becomes a flowing river of ice and snow. Such a "glacier" behaves very similarly to a river in its action on the land over which it passes, though its effect is more intense and its power of carrying boulders is much greater. As crevices or cracks form in the ice, huge masses of rock resting on the surface fall into them and slowly sink to the bottom. There they are crushed and ground and carried forward until the ice melts and most of its solid burden is left deposited, only the finest particles being carried forward by the water produced. The banks of a glacier are not so rough and irregular as those of a river, but are smoother and more rounded, the harder stones having curious scratchings on them, which are peculiar to glacier action.

The chief products of glacial action are large deposits of (*a*) heterogeneous non-plastic material consisting of an irregular mixture of sand, gravel, and large stones, and (*b*) a tough, plastic clay (known as Boulder Clay) which contains a considerable proportion of sand and gravel and a smaller proportion of pebbles.

Aqueous Action

The action of water in the form of rain, rivers, or the sea upon rocks is of three kinds—(*a*) abrasive, (*b*) solvent, and (*c*) a change in the colloidal state of the material (p. 18). By mechanical action water loosens crystals from a softer matrix, washes smaller or lighter particles away from the heavier masses, and by throwing one piece of rock against another it rounds them into almost globular pebbles. If water can enter beneath a piece of rock it may, in time, loosen it and cause a landslip.

Springs have an important epigenic action in many places, particularly near the coast, where it is usual to think of the erosion as the work of the sea. In reality, springs may do a large share of the work by loosening the soil and facilitating the later action

ıe sea-water. This is particularly noticeable on the coast 'ley (Yorkshire), in one part of which at every few hundred ; springs of water may be seen issuing out of the sandy cliff, .ng fissures in the soil and preparing it to be washed away au the next high tide.

The solvent action of hot water on silicates is relatively great, and hot springs frequently contain a large proportion of silica in solution, but the few warm springs in England are not of importance in the formation of sands.

Rivers and Streams act chiefly as abrasive and transporting agents in the disintegration of rocks. The material enters the water in various ways; it may fall in as the result of a miniature landslip, or after it has been blown away from its site by a gale; it may be washed in by the accumulation of many raindrops, each carrying its own grains of material; or it may enter as the result of the stream undermining its bank, parts of which then fall into the water.

On entering a stream, most fragments of rock are angular and irregular in shape, but during their passage they rub against one another and against the floor and banks of the stream, and so become rounded (unless of unusual hardness) and are gradually worn down. The particles thus removed form clay, sand, and gravel, and are carried forward more rapidly than the stones, which are either deposited at any point where the speed of the water is sufficiently reduced, or are carried onward until they reach the sea. The distances through which the finest particles may be transported are exceedingly great.

The amount of material transported by rivers is enormous, the Danube delivering some seventy million tons annually into the Black Sea. The amount of material carried depends on the volume and velocity of the water, and on the size, shape, and density of the solid particles. D. Stephenson has ascertained that the bottom of a stream of water moving at the rates shown in Table II. will move the materials mentioned in the third column.

Table II.—Size of Grains carried by Streams

Velocity of Stream.		Material moved.
Inches per Second.	Miles per Hour.	
3	0·17	Fine clay.
6	0·34	Fine sand.
8	0·45	Sand as coarse as linseed.
12	0·68	Fine gravel.
24	1·36	Pebbles 1 inch in diameter.
36	2·05	Stones the size of hen's eggs.

Under experimental conditions in the laboratory, water flowing

with a much lower velocity will carry away particles of clay and sand in suspension. Thus, in the mechanical analysis of soils it is customary to use a velocity of only 0·0072 in. per second for separating the clay, 0·28 in. per second for separating grains between 0·0004 and 0·001 in. diameter, and 0·61 in. per second for grains between 0·001 in. and 0·0016 in. diameter. Stones and other insoluble solid substances appear to lose about half their weight when immersed in water, and, consequently, large masses may be carried along by a stream which would not move them if they were not completely immersed. For this reason, also, the power of a stream is greatly increased during a time of flood, when both the volume and velocity of the water are much greater. Neither the surface velocity nor even the mean velocity of a river can be taken as a measure of its power of transport, but only the bottom velocity, that is, the rate at which the stream overcomes the friction of its channel. Rounded stones are most easily transported; flat angular ones are moved only with difficulty, as they present less surface to the current.

Owing to this continual grinding of the bottoms of streams and the undermining of the banks by the abrasive action of the stones and the solvent action of the water, the land through which a current of water travels is gradually cut away and forms gorges, chines, and valleys. A sudden drop in the ground forming the bottom of the river may form a cataract or waterfall, at the bottom of which the erosive force of the water will be still greater; the battering of the stones in the water gradually breaks down the weir and causes it to wear away slowly. Rivers thus tend to cut fissures and valleys in the land over which they pass, and also cause a levelling of the land over which they flow. In more level stretches of country—particularly if its course is winding—a river often alters its direction somewhat rapidly; this is due to frequent bends reducing the speed of the water and so permitting some of the sand, stones, etc., to be deposited. At every change in direction of flow the water with its burden of minerals impinges on the bank and gradually cuts its way on the outer edge in the bend of the stream; and as the speed of the stream is reduced at the inner edge of the bend, some deposition of material takes place. If the river cuts through the outer edge of the bend more rapidly than the matter which is displaced is deposited on the inner one, a short-cut channel is formed and a large portion of the original course, sometimes amounting to several thousand acres, is left dry.

Whilst all British rivers flow directly or indirectly into the sea, which thereby becomes the great receptacle for the mineral matters carried by them, there is an enormous proportion of sand and gravel which never reaches the sea, but is stopped at various points along the banks of the rivers, as just explained, and when the course of the water has changed, these deposited materials form beds which are of great value on account of the sand which they contain.

Sea-water produces a similar effect to rivers and streams;

but as its relative movement is very small at great depths, a much greater amount of deposition of mineral matter takes place. The force of the sea as a grinding agent is far greater than that of rivers and streams. Huge blocks of rock are churned and ground as in a monstrous mill and are reduced to pebbles and finally to sand and clay. The tide causes an almost incessant battering and washing away of material from the shore, and this is carried towards the more slowly moving parts of the ocean and there deposited. The action of the tides is most effective in the crevices between the rocks into which the water enters with almost explosive violence, at a pressure of two tons or more per square foot. Caves are hollowed out by the direct mechanical action of the water and of the boulders which it hurls against the shore during storms, and the enormous quantities of pebbles and sand around the coast form eloquent testimony to the force and power of marine action. The result of the action of the sea through countless ages has been the destruction of whole continents and the redistribution of the rock masses into new forms of material, which can scarcely be recognised, so greatly have they been changed.

Tidal and other ocean currents are also important agents in breaking up and transporting rocks and in sorting them into particles of varying sizes and densities. In addition to the sand produced by the action of water on rocks, some sand is produced by the action of the sea and other water causing shells to rub constantly against each other when moved by the water; such shells are gradually ground to powder, forming what are known as "shell sands" (p. 35).

Rain is the principal weathering agent in humid and temperate climates. Its action is due to the fact that on falling on to a rock it removes some of the ingredients by solution, and often leaves a crust of a soft and friable nature on the rock. This crust may be washed away by later rains and carried by the resulting streamlets for such a distance and deposited in such a manner that the various minerals removed may become quite separated from each other and may be deposited each in a relatively pure state; the larger pieces will be near their source, the sand will be graded into several degrees of fineness, and the clay and fine silt will be carried away from the rest of the material. This disintegrating action usually commences along any cracks or joints in the rock, these being particularly favourable to its destruction. In some cases the action is so marked as to make it appear as if the rock had been worn down by a river or stream.

Some rocks, such as dolerite and basalt, on weathering form spheroids, each having a succession of weathered rings. An unstratified rock having no fissures or cracks is much less easily weathered than a stratified rock, as the lines of stratification are lines of weakness and enable the weather to act quite rapidly; the joints are first corroded and cause the rock to break into large blocks and then to disintegrate still further, forming loose, incoherent

sands. The rate of weathering depends chiefly on the nature of the rock and on the character of the weathering agencies. In some cases a perfectly fresh surface is exposed, as in the case of limestones, whilst in others a thick crust of partially decomposed matter may cover the rock, as in the case of dolerites and basalts ; this crust partly protects the undecomposed rock and impedes its further disintegration. The rocks which are most resistant to weathering are those which consist of particles of an inert character cemented into a mass which is difficult to disintegrate mechanically. Siliceous sandstones are amongst the most permanent rocks, as they consist almost wholly of quartz with a siliceous cement, both of which are exceptionally resistant to weathering. Where, however, the rock is bound by a less resistant cement, such as one of a ferruginous, calcareous, or argillaceous character, disintegration is much more rapid ; the cement is more quickly removed, and in its absence the remainder of the rock falls to pieces, forming a loose, incoherent sand.

The chief action of rain water is that of a solvent, whereby it dissolves some of the constituents of the rock and removes them in solution, and this permits of the easier removal of the remainder by wind or by the mechanical action of water. This action is easily seen if the surface of a granite rock which has been exposed for a long time be examined ; the quartz crystals will stand out clearly, whilst the felspars have been corroded. This is due to the slightly acid character of rain owing to its containing carbonic acid in solution. When its action is long continued, as in rocks which are constantly exposed to the weather, the felspar is broken down, some of the alkalies being dissolved out as carbonates and carried away in solution, leaving a certain amount of silica free ; the strength of the rock is greatly reduced in this way and the grains are loosened, the action being further hastened by the fact that water containing sodium or potassium carbonate can dissolve silica and thus can remove some of the silica present in the felspar. In time the rock becomes entirely rotted and many of the felspar crystals are loosened and washed away from the quartz. In due course the quartz crystals will also fall away as their cementing medium or matrix is dissolved.

In this manner water first acts as a solvent in " corroding " the rock and afterwards mechanically removes the decomposed material, which would form a protective covering for the general mass of rock. The rain, however, keeps the surface of the rock comparatively clean by washing away much of the " corroded " material and thereby facilitates continued action.

Where such " corroded " rock material is deposited close to its source, having been transported only a short distance, it is sometimes known as *arkose*. It consists practically of the same minerals as the original material, though some of the finer grains (as of china clay) and some of the soluble substances may have been removed.

If any oxidisable materials are present they will be oxidised y contact with rain water, or, if the latter contains much humus, ome oxides may be reduced. The loosened particles are then washed out mechanically by further supplies of water as previously stated.

The general result of the action of water (of whatever nature) is to wear down the higher portions of the earth's surface, to grind down the large masses, and to transport the ground material to a lower level. Some of this material is carried in solution (as salt in sea-water), but by far the greater part of it is borne mechanically by the moving water. As soon as the velocity of the water is reduced some of the heavier particles begin to sink, stones and gravel settling out first, then the sands of varying coarseness or fineness, and finally the silt and clay.

The process of decomposition of granite rocks by the solvent action of water—especially of water containing acid in solution—is known by the general name *kaolinisation*, as one of the most important commercial products is kaolin or china clay. The felspar in the granite, when subjected to the solvent action of water, yields kaolin and free silica, the potash and some of the other bases being removed in solution; the particles of quartz, mica, etc., are thereby loosened and can be separated by exposing the rock to a stream of water. As clay consists of much smaller particles than sand, the clay is more readily carried away in suspension in the water, whilst the larger particles remain as "sand" and fragments of imperfectly decomposed rock. Whilst it cannot be supposed that such kaolinisation is the source of all primary sands, it is of sufficient importance to warrant further investigation. It is often followed by a process of separation, in which, as already indicated, the clay is wholly removed and re-deposited at a distance of several miles from the original location of the undecomposed rock. It is very difficult to estimate the precise importance of kaolinisation as one of the original causes of the formation of sands from igneous rocks, as the subsequent processes of Nature which have occurred have, in most cases, destroyed all vestiges of the original rock.

The solvent action of water is of great importance in the disintegration of many rocks. There is scarcely a mineral which is not slightly soluble in water, and many substances are dissolved readily, so that the contact of water with rocks is certain, in time, to remove some of their constituents. If the water contains any acid (as carbonic acid derived from the air) or other chemically active material, its action is greatly increased. Thus, chalk and its related rocks are scarcely affected by pure water, but are readily dissolved in water containing carbonic acid. Under some conditions, rain water containing carbonic acid can also decompose certain silicates and render them soluble.

Many siliceous minerals, such as felspars, hornblende, olivine, muscovite, etc., are attacked by carbonated water and are gradually

decomposed, liberating alkalies, free silica, etc. Some of the silica is dissolved and carried away in solution and deposited as a cement in other rocks. The soluble carbonates produced by the action of carbonated water on rocks are precipitated in lakes or in the sea and produce limestones, dolomites, etc.

The presence of minerals rich in iron is a frequent cause of the disintegration of rocks, the iron being oxidised and partly dissolved, thus rendering the remainder of the mass more readily disintegrated. Any rock rich in lime may have its lime converted into carbonate and removed in solution. Sulphides may be converted into soluble sulphates and sometimes into free sulphuric acid.

Many spring and well waters are rich in dissolved salts of various kinds, such as the medicinal waters of Harrogate, Bath, etc., the various chalybeate (iron-containing) waters, and the "hard" waters which are heavily charged with calcium bicarbonate and sulphate formed by the action of dissolved carbon dioxide on limestone or chalk and by the solvent action of water on gypsum. Sea-water owes its saltness to the materials which have been dissolved out of various rocks and have been delivered to the sea by streams and rivers. As the various seas have no outlet except by the evaporation of the water (in which case the dissolved salts are not removed), sea-water must continue to increase in saltness.

Frequently water dissolves out certain constituents of a rock without altering the crystalline form of the mineral, yet completely changing its composition. In such minerals (termed *pseudomorphs*) clay may take the form of rock-salt, silica that of wood, and many other striking examples might be mentioned.

The chemical action of water on mineral substances (hydrolysis) has been studied much during recent years. It is now recognised that water contains free hydrogen-ions (H) and free hydroxyl-ions (OH) under certain conditions, and that its dissociation into these two kinds of ions is sufficiently powerful to decompose certain minerals such as mica, felspar, etc., and thus to produce alkaline solutions.

The action of the water may be represented in the case of a simple silicate by

$$Na_2SiO_3 + 2H \cdot OH = H_2SiO_3 + 2NaOH,$$

a weakly dissociated silicic acid being formed, together with caustic soda. The latter gives the alkaline reaction.

Through the formation of undissociated silicic acid a loss of hydrogen-ions occurs, and to restore equilibrium this must be made good by the dissociation of more water, which is then able to attack more silicate, if present.

The alkaline silicates are most strongly affected by water, then the calcium silicates, but those of magnesia are scarcely affected at all.

As in most cases of chemical action, the influence of time is

important. The solutions formed by the action of the water on the rocks are so dilute that the velocity of the reactions which occur is sometimes so slow as to be almost inappreciable, yet so long have they been acting in many cases, that incalculably large masses of material have been completely changed. On the other hand, the action of rain on some materials—such as basalts and olivine—is very rapid. The rain water (rich in carbonic acid) soaks into the mass and converts the lime, magnesia, soda, potash, and ferrous silicates into acid carbonates. These carbonates are washed out of the rock, together with the silica set free during their formation.

The change in the colloidal state of some minerals as a result of the action of water is sometimes of great importance. A mineral consisting of coarse particles may be ground so finely by the abrasive action of the water that the resulting particles become too small to sink and take on new properties, inasmuch as they form colloidal suspensions or sols. These particles are so minute as to be excluded from the definition of "sand." When such minute particles are brought into contact with others bearing an electric charge of opposite sign (such as humus), both are precipitated, and under favourable conditions a colloidal gel is formed. Colloidal gels appear to possess a honeycomb or "space-lattice" structure and are able to absorb many times their weight of water, forming a gelatinous mass. Silica and clay are particularly prone to enter into the colloidal gel state, and many of their properties are due to this fact (see Chapter V.).

Organic Action

The action of plants and animals in the formation and dissociation of rocks is important. Roots constantly penetrate into crevices, and if the ground is sufficiently soft they break it up, forming soil, and the decayed remains of plants and animals are constantly adding to the soil. The action of *decayed plants* is somewhat complicated. The first products of the decomposition of plants are humic acids, which by bacterial and other actions are later decomposed into carbon dioxide and water, together with nitrogenous compounds such as ammonia, nitrites, nitrates, and nitric acid. These compounds exert a chemical action on the rocks with which they come in contact and so disintegrate them.

Bacteria play an important part by oxidising dead vegetable matter through intermediate stages to carbonic and nitric acids, which later have a chemical action upon many rocks. Bacteria also act in other ways, such as decomposing iron sulphides and carbonates and forming iron oxide.

An important action of bacteria and other low forms of life is the production of humus and other substances which flocculate any colloidal sols with which they come in contact, and so increase the amount of colloidal gel in the rocks and especially in the soil.

This is a subject of which very little is known, but numerous investigations are now being made upon it (see Chapter VI.).

Weathering

The term weathering is convenient as including all those changes which occur as a result of the action of heat and cold, rain, hail, snow, wind, exposure to air, and other atmospheric processes in rocks and other substances. The general tendency of weathering is to destroy the form of all materials and so rearrange their constituents as to form new substances. Thus, most granites will, on sufficient exposure to weather, break down into a mixture of mica, quartz, clay, and other minerals, together with some undecomposed felspar. This destruction is brought about by the agencies already described and may require an enormous period of time ; it is largely a matter of fortuitous circumstances whether the products of the action of the weather remain together or are separated from each other, as when the clay and mica are washed out of the mass into separate hollows or pockets.

The extent to which weathering occurs depends on the nature and situation of the rocks, soft porous materials in exposed positions being most affected. Granites vary greatly in this respect. Rose has pointed out that many rocks which are unaffected by the most powerful acids in laboratory experiments weather readily in nature under the apparently feeble influence of water, air, and carbonic acid. This is due to the influence of the much larger quantities taking part in the reaction, and is a typical example of "mass action." Very dilute solutions—being more completely dissociated into ions—are in fact relatively more active than strong solutions, but are much more difficult to investigate in the laboratory.

The appearance of rocks is often useless as a guide to the probable extent of weathering, as some granites and basalts form superficial crusts several feet in thickness (due to removal of alkalies in the former and lime as carbonate from the latter) ; when these crusts are detached by the action of the wind and rain, they form deposits —often of great thickness—of a character entirely different from that of the original rock. In other cases the weather exerts a selective action, so that some fossils and nodules can be more readily picked out of a weathered rock than a freshly exposed one.

Most rocks weather in a characteristic manner which facilitates their identification even at a distance. This disintegrated matter may form "soil" on the site, or it may be removed to another site by rain or other influence.

The individual substances produced by the action of the weather are often the result of a highly complex series of reactions, both direct and reversible. A more detailed study of these involves so deep a knowledge of the laws of dilute solutions, mass action, etc., as to be beyond the scope of the present volume.

From the commercial point of view, the chief effect on rocks of the weather is the formation of clays and sands. The nature and composition of the products formed depend to a large extent on the minerals composing the rock. Quartz is scarcely affected by weathering, and most of it remains behind after the other minerals have been removed in solution or have been decomposed. Felspars are frequently left behind, though they are to some extent attacked with the liberation of free alkali, which is removed in solution. Mica is very little affected as a rule, though the pyroxenes and amphiboles are more easily decomposed. Some crystalline minerals, such as garnet, staurolite, tourmaline, sillimanite, and kyanite, are not attacked but are removed by aqueous transportation and are found scarcely corroded in some detrital sediments. The heavy minerals, such as magnetite, ilmenite, chromite, rutile, zircon, and metal-bearing minerals generally, are only slightly affected by weathering.

It will thus be seen that the primary sands are produced by various actions, as a result of which the original igneous rocks are decomposed in various ways, the bond which forms them into a compact mass is destroyed, and any fine material, such as clay, which may have been produced is washed out by aqueous action, leaving behind a loose deposit of grains of the different minerals composing the original rock. When such a deposit is more or less protected from any weathering action, or where very little weathering occurs, such a bed may remain in its original condition indefinitely, but in most cases primary sands are transported to other locations, rearranged, separated, and so eventually form different deposits.

The disintegration of rocks gives rise to particles of various sizes, from large boulders and pebbles to sand, dust, or mud. The larger ones, such as boulders and pebbles, do not concern the reader of the present volume until they have been still further disintegrated into smaller particles of various sizes, except where they are found close to or amongst the finest deposits, as in those formed by torrential rivers and the littoral deposits along certain sea coasts. Glacial deposits also contain a large proportion of boulders which may or may not be mixed with finer materials (p. 11).

THE FORMATION OF SECONDARY DEPOSITS

After the primary sands have been formed by the decomposition of igneous rocks, they tend to accumulate in the form of secondary deposits as the fine particles gradually settle to the bottom of the streams, rivers, glaciers, lakes, or seas in which they were carried in suspension. To some extent, also, particles of primary sand carried away by the wind form secondary deposits when the velocity of the air is reduced sufficiently to cause the air-borne particles to be deposited. It will thus be seen that the action of

rivers, lakes, seas, earth movement, wind, and a variety of other forces which tend to the removal of the primary sands to some distance from their place of origin, also plays an important part by depositing them in beds of varying thickness and purity and of a density varying from a loose surface deposit to a compacted sandy rock. These deposits may, in turn, be further changed, classified, and transported until all trace of their original form is lost, so that, although the destructive action of various natural agencies has been chiefly emphasised in the foregoing pages, the influence of such forces in collecting the particles of primary sands is equally important. The grains of sand which have been produced by the decomposition of igneous rocks are gathered together by many of the same agencies which aided in the disintegration of the rocks from which the grains were produced, and the grains so separated are deposited according to the density of the particles and the special features of the district through which they are carried.

THE FORMATION OF TERTIARY AND OTHER DEPOSITS

The sands collected and formed into secondary deposits sometimes undergo further metamorphoses and are converted into quartzites, and other sandstone rocks, limestone, flints, carbonates, etc., in which the grains of " sand " are united together by a natural cement—usually of amorphous silica—produced by the infiltration of liquids containing siliceous, calcareous, ferruginous, or other substances in solution. These rocks may, in turn, be decomposed by the natural agencies previously mentioned, with the result that sands are again formed, though they may be different in character from the primary or even the secondary sands.

The processes of disintegration and building up of rocks may be repeated to any extent, and are continually in operation. They have resulted in the production of many sands of extremely complex nature, which offer many highly interesting problems to the mineralogist. Fortunately, most users of sands need not concern themselves with such matters, though it is important to know sufficient of the origin of sands to appreciate such problems when they arise.

THE AGGREGATION OF SAND DEPOSITS

The principal agencies which aid in the collection of sand so as to form deposits are :

1. Wind.
2. Water, including rivers, seas, tides, etc.
3. Glacial action.

All deposits of sands, other than primary, may conveniently be classified according to the chief agent in their deposition, viz. :

1. *Aeolian*, or deposits formed by air (wind).
2. *Fluviatile*, or deposits formed by rivers.
3. *Estuarine* or *Fluvio-marine*, or deposits formed at the mouth of rivers.
4. *Lacustrine*, or deposits formed by lakes.
5. *Marine*, or deposits formed by seas.
6. *Glacial*, or deposits formed by glaciers.

Aeolian Sands

The action of wind in gathering together the particles of sand is very important in exposed, dry situations, *i.e.* deserts, some sea coasts, etc.

In deserts the sandy materials are principally produced by dry weathering, *i.e.* by the bombardment of rocks by wind-borne particles, resulting in the production of small detached particles which are, in turn, carried by the wind and employed for the further disintegration of rocks.

True desert sands often originate by the simple breaking up of crystalline rocks into their constituent grains, without any perceptible alteration in the minerals themselves. When the air has reached a locality where there are no rocks and where its velocity is sufficiently reduced, it deposits the particles. Sometimes these particles are again carried by the wind and re-deposited. In this way, in the course of time, vast accumulations of sand are concentrated in situations where there is the least disturbance, and there they form large beds. Where the winds are irregular in their action, large tracts of country are gradually covered with wind-blown sand which is constantly shifting or drifting in the various directions taken by the wind. According to Flinders Petrie, 8 ft. of soil has been swept away by the wind in Egypt during the last 2600 years, or nearly 4 in. per century.

A certain amount of separation or grading of the sand is also produced by wind action. The larger particles which are less easily carried by the wind are moved less frequently, whilst the finer particles are carried about and are sometimes moved over considerable distances, so that, in time, the deposits become roughly graded, the finer particles being on the surface and the coarser ones lower down. Thus, if the surface sand deposits on deserts are examined they will be found to be very uniform in size on account of the sorting action of the moving air. According to some experiments by J. A. Udden, the action of a wind travelling at eight miles per hour on particles of various sizes is as shown in Table III.

The maximum size of grains carried by normal winds is about 2 mm. diameter, but during storms much larger particles may be carried by the air.

It is interesting to note how the prevailing winds have accumulated sand deposits in different parts of the world. The great desert belt stretching from the Sahara in Africa right across

TABLE III.—SIZE OF GRAINS CARRIED BY WIND

Average Diameter of Particles.	Behaviour of Grains.
mm.	
0·75	Described a path diverging about 10° from a vertical line.
0·37	Described a path diverging about 45° from a vertical line.
0·18	Described a path diverging a few degrees from horizontal.
0·08	Scarcely noticed to settle in transport.
0·04	Apparently completely borne by wind.
0·007	Completely borne up by wind.
0·001	Completely borne up by wind.

Arabia is one of the hottest parts of the world, and consequently the air surrounding the area tends to rush towards this hot desert to occupy the space of the heated air rising from it. For this reason there has been little chance for the sands produced by disintegration of the rocks in these areas to be distributed, and, consequently, they have accumulated and formed large tracts of desert. A large part of the Sahara consists of a white or yellowish sand, often mixed with gypsum, forming dunes 50-400 feet high, the rocky floor being sometimes exposed. The dunes appear to be more permanent than those in more northern latitudes. During storms much sand is carried from one dune to another, or a chance obstacle, such as a dead camel, may form a nucleus, but the general arrangement of the dunes remains constant. The dunes along the caravan routes are sufficiently permanent to possess names. As a rule, the distance from crest to crest of the dunes is 0·5-1 mile. Individual dunes slope gently on the windward side, and have a very steep slope to the leeward, on account of the scooping action of the air currents behind their crests. The surface of dunes is often diversified by secondary ripples.

Observations in Egypt have proved that the desert sand is heavily charged with positive electricity. Fifty per cent more ozone was found in the air over the desert than in the oases.

There is little rain in desert countries, but a certain amount of water in the rock is held by capillary action. The hot rays of the sun draw this to the surface, bringing with it soluble salts of sodium, magnesium, etc. Chemical reactions occur between these hot solutions and the constituents of the rocks, so that the latter are decomposed from within. This process leads to the cementation and solidification of some loose sediments and the colouring of many desert sands, which are usually red. It also results in the saturation of many desert sands with soluble salts which sometimes form an efflorescence on the surface.

The formation of desert sands may not be entirely due to dry denudation, but it is certain that the wind has played a large part

in the formation and classification of the present surface deposits in the larger deserts.

The fine sand of deserts is often blown high and carried for great distances by aerial currents; finally it descends in the form of "red fog," "sea dust," or "sirocco dust." According to Geikie, it is occasionally so abundant as to obscure the sun and to cover the decks, sails, and rigging of vessels which may be a thousand miles from land. Much dust has been carried from the Sahara and deposited in the Mediterranean district and the Canary Islands, and it is said that some of the sand in these deposits may have come from South America.

Volcanic dust is also carried in this manner, showers from Iceland having been deposited in Scandinavia, and some Krakatoa dust has even been carried to Europe. Large quantities of diatoms have been carried thousands of miles by wind.

The amount of separation or grading effected by wind action depends on (*a*) the size of the particles, (*b*) their shape, (*c*) density, and (*d*) the speed of the wind.

When all the particles are of the same material and are similar in shape, the amount of separation effected in transit will depend largely on the speed of the wind, but where grains of different materials occur, as is the case with quartzite sands containing heavy detrital minerals, the density of the latter largely determines the nature of the separation effected. In such a case, comparatively large particles of quartz may be blown away, whilst much smaller particles of zircon, rutile, etc., may, on account of their greater density, remain behind.

In the case of shell sands, the shape very largely determines the extent of the separation which occurs. The grains are largely tubular, lenticular, or disciform, and a blast of wind may strike such grains under their flat surface and carry them to great distances, while the same blast would not move more rounded grains of the same bulk which rested beside them. Carus Wilson has noticed that associated tubular calcareous grains have been separated from the rounded grains of "killas" by the action of the wind.

The great accumulations of *blown* sand occurring along the coasts are of essentially the same character as the sand dunes of the deserts, except that they consist of particles produced by marine and fluviatile denudation rather than those produced by a dry wind erosion, such as is the case with desert sands.

The particular method by which nature works in the forming of sand hills on the seashore may here be briefly described. (1) Frosts tend to split rocks, and (2) the chemical action of the rain dissolves the binding elements in the rocks and liberates quartz or other insoluble grains. (3) Rain and rivers carry these grains to the sea. (4) Tidal currents deposit them on some adjoining coast, usually about the time of high water when the tidal action is at rest. (5) Wave action breaks up the surface of the shore by the fall of each wave, the result being a translation

from low- towards high-water mark of a larger number of grains than the backwash of the wave carries back. (6) The drying of the shore by sun and wind agencies. (7) The lifting of the dried sand and its transportation by high winds until it is brought to rest by obstructions in the form of wreckage, cliffs, sand hills, etc. Such obstructions may start not only a sand hill but a new range of hills some distance away from the previous seaward line of hills. Examples of this action are common along the Lancashire coast from Freshfield to Southport.

In order that sand dunes may be formed in large amounts, the following seven conditions are required, according to W. Ashton ; if any are absent, sand hills will not be formed or will be insignificant in extent :

1. Contiguity to a coast on the windward side, which is in process of marine denudation.

2. Contiguity to mouths of rivers draining Millstone Grit or similar formations.

3. A low flat shore.

4. A coast of such a formation as not to be easily disintegrated, such as true sand, and not of clay or chalk.

5. The growth of star grass or other vegetation. Vegetation promotes hill-growth by the binding together of the sand, and even more by the grains being caught by the long blades of grass, etc. These grains fall in the lee of the plants, which push their way upwards so long as they can obtain a supply of moisture for their roots. Windy months which happen to coincide with the grass-growing period of the year are the most favourable to rapid hill-growth.

Other sand binders are *Salix repens*, var. *Argentea*, or Silver Willow, found between Birkdale and Formby; *Triticum repens*, or creeping wheat grass, a smaller grass of blue-green colour which grows above high-water mark at the foot of hills ; and the sand sedge, *Carex arenaria*; sea holly, sea spurge, saltwort, and sea rocket.

In Cornwall, wild thyme has been found a satisfactory substitute for star grass. Sir Hyde Page, a noted engineer of his day, found the planting of gorse bushes an effective check to blowing sand.

On the coasts of Norfolk, the Moray Firth, Norway, and Jutland, maritime pines have proved very effective in stopping sand drift. On the margin of Southampton Water, "Spartina" grass has proved very successful.

6. A coast in general line with the prevailing winds. This condition is of great importance. The most favourable direction for the prevailing winds to strike a coast is at an angle of 10 or 15 degrees ; they then have the maximum power of transmitting sand from the foreshore. Whenever extensive ranges of sand hills are found, this condition is invariably present.

7. Sea-wave action which brings in sand from the sea.

The sand carried by the wind impinges on the blades of star

grass, drops in their lee, and they continually push their way up through the accumulated drift. At a height of about 60 feet the sand can no longer draw up sufficient moisture by capillary action to serve the plants, and when these die there is nothing to retain the sand, so that there are few sand dunes more than 60 feet in height. On the coast of Norfolk, sand hills 50-60 feet high occur; on the coast of Holland, some of the dunes are as much as 260 feet high.

The breadth of the sand beds on the coasts varies from 3 to 5 miles. The form of sand dunes depends entirely on the intensity and direction of the winds which produce them. In some cases the sand is heaped up into mounds in rows; in other cases the dunes form long, narrow ridges. When the speed of the wind is great they form at right angles to the direction of the wind, but where the intensity is less they may form parallel to its direction. In Central Asia the sand frequently takes a crescent-shaped form, the convex side facing the wind. Where the wind is irregular the sand is merely piled in irregular masses.

Sand hills are chiefly found on the portions of the coast which are exposed to the prevailing winds, the most important of those in Britain, therefore, being on the west and south-westerly coasts, as in Devonshire, Wales, Cumberland, Lancashire. The last named forms a good example of wind-blown sands. The material composing these beds has been derived from three sources:

1. Sea-eroded material from the Cheshire and adjacent coasts.
2. Fluviatile material.
3. Tidal material due to the shallowness of the sea on this coast.

The chief source is undoubtedly the second, viz. river-borne material from the higher parts of the Pennine Range where the rivers Ribble, Irwell, and Mersey rise. Repeated micro-examinations of the sands by J. Lomas prove conclusively that they are derived from the Millstone Grit formation. As the Pennine rocks are denuded, the clay is deposited on the Crossens shore as "slutch," and the greater part of the sand is deposited in sand banks at the mouths of the Dee, Mersey, and Ribble. Sea currents, the tides, sun, and wind do the rest in piling the sand into dunes along the north-western shores of the Mersey and the Ribble.

The mean direction of the prevailing winds just south of west is well indicated by the inclination of the trees in unsheltered positions along this coast. Twenty years' records show that nearly all the winds of sand-lifting force come from the south-west and west. The hill ranges accordingly show a steep side on the west-south-west or prevailing wind side, whilst on the leeward or landward side a long slope is usually developed.

Among other extensive sand-hill ranges in Britain are those found on the north coast of Cornwall and between Nairn and the river Findhorn in Scotland. The largest sand-hill ranges elsewhere are found on the Ayrshire, Aberdeenshire, Lincolnshire (very low), Norfolk, Suffolk, and Glamorganshire (very high) coasts.

In some places, as in Cornwall, much of the blown sand is composed of comminuted sea-shells. In Bermuda and other coral islands, fine coral sand with comminuted shells has been formed into dunes by the wind and cemented by rain water, forming compact rocks.

Deposits of blown sands are by no means always stationary, and, where changes in the direction of the wind are frequent, large tracts of land may be overwhelmed with sand and then cleared again, as at Santon Downham, east of Brandon, where sand storms or sand floods have at various times swept the country. At St. Pirian a church which had been smothered for seven centuries was uncovered in 1835 by the natural removal of the sand by the wind. The dunes in the Bay of Biscay, where they are not held by vegetation, travel inland at about 16½ feet per year, and in Denmark at 3-24 feet per year.

The speed with which entire hills will sometimes be shifted was exemplified during a westerly gale in 1911, when, according to D. Pennington, a high hill between Freshfield and Ainsdale, near Massem's Slack (Lancashire), was bodily moved between 100 and 150 yards. Near the same spot and in the same year a curious find was made in the hollow of the outer line of slacks about a mile to the north of Freshfield Perch. Gales having drifted away the sea face of a long sand hill, on the landward side of the hollow the remains of seven wrecks of wooden vessels, apparently from 200 to 250 tons, were exposed to view; two days later all but one were buried in the sand.

When fixed by vegetation, sand hills have, on many coasts, a high value as natural protectors of low-lying lands from inundation by the sea.

The deposits of fine detritus occurring in different parts of the world, and designated under the general term "loess," are thought by some to be of aeolian origin and by others to be produced by aqueous action (p. 31). According to Richthofen, the Chinese deposits are largely composed of a fine dust, probably derived from a fluvio-glacial period and subsequently desiccated during a time of dry climate, the dry dust being afterwards transported by the wind to the river basins and plains of China.

The Keuper sandstone round Birkenhead and Stourton consists of desert sand which has been consolidated and made into a solid rock. On weathering, this rock disintegrates and forms a loose sand similar to other deposits of wind-blown sand.

Aeolian deposits sometimes extend over wide areas, but are often of an irregular and discontinuous nature. Their thickness is usually very variable, and they often exhibit cross- or current-bedding. Ripple-marks sometimes occur and are useful in ascertaining the mode of origin of the sand.

Sand hills sometimes grow rapidly; H. T. Crofton has observed that under favourable conditions those at St. Annes grow at the rate of over 2 feet per annum, the greatest increase occurring in

the more windy months of March, April, and May. T. Mellard Reade calculated that about 105,000 cubic yards of sand are moved every year by the wind on 16 miles of the South Lancashire coast. About 2600 years, at this rate, would account for the entire deposit. J. Lomas, in a paper before the British Association in 1903, expresses the opinion that 400 years ago there were no sand hills on the Lancashire coast. They began to form at Formby at the end of the seventeenth century, sanding up the deep channel near the ancient port of Formby and thus increasing the sand-drying area, which afterwards extended rapidly northwards. As the high-water mark was rapidly driven back, successive ranges of sand were formed on the seaward side, until now some of the sand hills between Formby and Ainslie are nearly 80 feet high. This process still continues. The lateral growth of these ranges is surprisingly rapid; near the Palace Hotel, Southport, ranges 20-27 feet high, with a maximum width of 190 yards, have been formed since 1885. Although these hills are of recent origin, the sand of which they are composed is much older, much of it being at least 2000 years old.

The sand hills at St. Annes appear to have been formed in a similar manner; the main channel of the Ribble has gradually moved northward, piling the sand brought down by the water on the north shore between Fairhaven and South Shore through the action of the prevailing winds. The range of modern sand dunes from Blundell Sands to Churchtown appears to have a different origin and to be due to a change in the course of the Mersey about a thousand years ago.

Aeolian or wind-blown sands often consist of small angular grains, but those derived from the seashore in the manner just described are usually rounded. (See also Chapter III., under *Blown Sands* and *Shore Sands*.)

Fluviatile Sands

Fluviatile deposits are those which have been formed by the action of running water. These deposits accumulate as a result of a decrease in the speed of the current, as at a sudden bend in the path of the stream or where the river joins the sea, the contact with salt water causing the deposition of some of the grains; the ordinary sand deposits in the beds of most streams and rivers belong to this class. In some cases the rate of deposition may be so great as to turn a stream out of its course or even to divide it into two parts flowing round the deposited detritus.

Fluviatile deposits may be formed on river banks and flood plains when the waters of a river are in flood and the speed is so great as to cause the detritus carried along by the current to be lifted over the banks of the river and deposited over the low-lying area on either side. Such plains of alluvium occur in many tropical countries where, during the rainy season, the rivers are accustomed to overflow their banks.

Sometimes terraces are formed on either side of a stream. As the bed of the stream is gradually lowered by erosion the flood level will decrease, so that as time passes the alluvium will be confined more and more to an area nearer to the bed of the river, forming a series of terraces of decreasing height as the bed of the river is approached.

In this country it is common to find three such terraces, but sometimes as many as six, seven, or even more may occur.

In North America this mode of sedimentation of alluvium has taken place on a very large scale; the Mississippi alluvium from the mouth of the Ohio to the Gulf of Mexico, occupying an area of 19,450 miles, is 25-40 feet thick.

Fluviatile deposits may also be accumulated at the foot of mountain streams, waterfalls, etc., the decreased speed of the water causing the deposition of some of the material held in suspension or carried along by the force of the current. Such accumulations frequently take the form of cone-shaped deposits which are sometimes of great extent, some being many miles in diameter and hundreds of feet thick. Such alluvial fans occur in India and on the flanks of some of the ranges in North America.

Owing to the manner in which they are produced, fluviatile sands are usually very variable in composition and consist of irregular mixtures of particles of all sizes. Such deposits are found in many Cretaceous and Tertiary deposits around the Dartmoor and Cornish granites. The disintegrated materials, consisting of quartz, felspar, tourmaline, etc., which were carried by the numerous streams from the hills, became suddenly arrested in lakes and slow-moving rivers, with the result that much material was thrown down with no respect to the sizes of the particles, the deposits being very often fan-shaped in form. On the other hand, many rivers exert a marked sorting action, and thus produce various metalliferous deposits as well as beds of sand and clay. This is due to the fact that most of the metal-bearing minerals are so heavy that they are not readily moved by water currents, and consequently tend to become concentrated, whilst other "lighter" minerals are washed away, the residue forming "mineral placers." Many valuable minerals are obtained from deposits of this kind, including gold, zircon, platinum, tin, tungsten, as well as various gems. Thus, in Ceylon there are beaches with alternating layers of pink garnet and black ilmenite, whilst monazite occurs in the river beds and beach sands of Brazil, Travancore, and Ceylon.

Fluviatile deposits are not usually so extensive as estuarine ones, and they may vary considerably in thickness in different parts of the beds on account of variations in the speed of the river and other causes. They also often exhibit stratification and frequently cross- or current-bedding. Conglomerates are generally of fluviatile origin, but they may also be formed on the shores of lakes and seas.

Fluviatile sands are usually "sharp" and consist of irregular

fragments of numerous sizes. Whilst quartz is usually the predominant mineral, others may be present in various proportions according to the conditions under which the rivers or streams obtained the minerals from which the sands are derived, and according to the treatment such minerals have undergone during transportation. (See also Chapter III., under *Fluviatile Sands.*)

Estuarine Sands

Estuarine deposits are formed at the mouths of rivers in the form of a delta; they consist of successive layers of material carried down by the river and deposited. A delta only forms where the conditions for its formation are favourable; where the sea at its junction with the mouth of a river is very deep, the suspended matter may sink to the bottom and not appear; where there are strong currents, the detritus may be entirely removed before it can form a delta.

Deltas may be of great extent, that of the Mississippi covering an area of over 12,000 square miles, whilst that of the Ganges and Brahmaputra occupies between 50,000 and 60,000 square miles, and is over 480 feet thick.

Estuarine deposits may also be accumulated by bars and lagoon barriers, the water being arrested in its flow, and consequently depositing much of the solid matter held in suspension. As the sediment deposited near the mouth of a river accumulates, it acts even more effectively than the sea in arresting the material carried down by the river. "Bars" of this kind sometimes attain great sizes, and may be moved farther out to sea by floods or pushed up-stream by storms. Such bars occur in several places in this country, including Start Bay in Devon and between Mumble Rocks and Swansea. Every river has its estuarine deposit, but in many cases the sea removes so much of it that the residue is insignificant. The material so removed may form a *fluvio-marine* deposit in some other location.

The principal estuarine accumulations include rocks, stones, gravels, sands, silt, and mud, and possibly loess. These deposits usually contain a greater or less proportion of clay, the amount depending on the velocity of the water. If the current is rapid, the estuarine deposits may be comparatively coarse, most of the fine material being then carried farther out into the sea and forming marine deposits. With a very sluggish river, however, much clayey material may settle along with the gravel, sand, and silt.

The extent of estuarine deposits varies according to the size of the estuary, but they are sometimes very large, and are remarkably uniform in thickness over the greater part of their area. A peculiar feature of estuarine beds is the rapid alternation of layers of different materials, due to changes in the speed of the rivers at different seasons of the year. In times of flood, coarse material

may be carried much farther and deposited upon a bed of comparatively fine material.

In this country there are several extensive estuarine deposits in Lincolnshire and Northamptonshire. Some of them contain so large a proportion of clay as to be useless so far as sands are concerned; the beds at Great Weldon, Northamptonshire, and also at Kettering and Wellingborough, are of this character.

The *loess* or *lehm* which occurs over a large area extending eastwards from the north of France across Europe and Asia into China may be of estuarine origin, though it is thought by some to be an aeolian deposit (p. 27). The *adobe* of America is of estuarine origin, as are also the *black earth* of Russia and the *regur* of India.

Estuarine sands usually consist of moderately angular particles of various sizes. They closely resemble the fluviatile sands in many respects, and, apart from their situation, it is almost impossible to distinguish them from the latter. (See also Chapter III., on *Estuarine Sands.*)

Lacustrine Sands

Lacustrine deposits are of the same nature as estuarine deposits, except that they are characterised by greater uniformity on account of the smaller amount of agitation to which such deposits are subjected. Lakes are, in fact, great settling tanks in which the rivers discharging into them deposit their burden of clay, sand, and other minerals. As the smaller particles are carried the farthest, lacustrine deposits are usually deepest and coarsest at the inlet of the lake, the finest particles being deposited farthest away. Where a river runs through a lake and passes out at the other end, the result of contact with the waters of the lake is very obvious. Thus, the river Rhone enters Lake Geneva charged with detrital matter and appears quite turbid, but on leaving the lake it is translucent and blue, the material in suspension having been deposited in the lake, chiefly near the end where it entered. Thus, lakes may act as filters and intercept the sediment carried into them by rivers. Large deltas are sometimes formed by material deposited in this way, many examples of this action being found in Switzerland and other localities. As the deposition of the material continues, the lake gradually becomes full and may, eventually, form "dry land" with a stream running through a portion of it. If the stream be diverted as the result of some earth movement, a dry lacustrine deposit is formed.

As the deposition of material in a lake is a function of the speed of the water and the size of the particles, the separation of the gravel, sand, and clay is often very complete, the strata of each being clearly defined so long as the flow of the river feeding the lake is fairly constant. In times of storm, on the contrary, when the speed of the water is greater, the coarser particles are carried farther, and in this way a considerable amount of gravel may

e deposited simultaneously with the sand forming a diluvial .eposit.

The New Red Sandstone of Cheshire (known as Bunter Sandstone on account of its variegated colour) consists of a consolidated bed of lacustrine sand laid down in fresh-water lakes. These deposits are at least 200 feet thick, and show clearly the importance of lakes in the formation of sand.

Lacustrine sands are usually composed of grains of fairly uniform size; they are moderately angular, but are sometimes well rounded. (See also Chapter III., under *Lacustrine Sands.*)

Marine Sands

Marine deposits consist largely of material produced by coastal erosion mixed with that brought down by rivers and glaciers and with shells and other materials of a calcareous nature, derived directly from the sea, and, in some cases, with volcanic ash and dust. Three types of marine deposits may be readily distinguished: (1) those under the sea, or *pelagic* beds; (2) those under the foreshore, or *littoral* beds; and (3) those now at or above sea-level, but originally below it, and generally referred to when the term *marine* is applied to sands.

Pelagic deposits usually consist of very fine material comprising calcareous mud, volcanic dust, sand, and clay, with occasionally a small proportion of coarser material. Such deposits are of various grades from sands to "oozes," the latter term including the Radiolarian and Globigerina oozes. Pelagic deposits are usually subdivided into those formed at a depth exceeding 100 fathoms (abyssal deposits) and those formed in shallower water. The latter are, with local exceptions, of a heterogeneous character, whilst those formed at greater depths are of a very fine and muddy character, though often containing a small quantity of material of a coarser nature.

The deposits known as *sea sand* usually extend out to sea and cover almost the entire floor to a depth of about 100 fathoms, except near the mouths of rivers and estuaries, where silt and mud are also deposited near the shore.

The abyssal deposits or oozes scarcely come within the scope of a volume on "sands," but they may be briefly described; they consist of a fine material discharged by rivers, etc., into the sea, the coarser particles having been deposited nearer the shore, together with materials produced by the disintegrating action of the waves on the coast, volcanic dust, meteoric fragments, and the siliceous and calcareous skeletons of dead marine organisms, including diatomaceae, sponge spicules, foraminiferae, pteropods, etc., the first three having siliceous and the last two calcareous skeletons. Owing to their solubility in sea-water under pressure, calcareous organisms do not occur at depths below 3000 fathoms. Siliceous skeletons are, however, less soluble, and

occur at the greatest depths of the ocean yet examined (over 5000 fathoms).

At the greatest depths, a red clay predominates, owing to this remaining in suspension after all the other materials have settled, but many deep-sea deposits contain a large proportion of sand; they frequently contain no argillaceous matter, and consist wholly of non-plastic particles. On account of their consistency when drawn to the surface, deep-sea deposits are frequently termed *muds*, though some of them are not plastic like most muds found on the surface of the ground.

Volcanic muds occur widely in the Western Pacific, and consist of fine fragments of lava, organic calcareous matter, and some clay. Near the coasts they may be classed as sands, but at greater distances from land they pass gradually into the other forms of mud and finally into abyssal ooze.

Sands composed chiefly of foraminiferae, radiolaria, diatoms, sponge spicules, and other organic remains occur to a varied extent in various deep-sea deposits. Quartz is generally absent from them.

Pelagic and abyssal sands are not accessible except in very small quantities. The particles of which they are composed are usually extremely minute and (with the exception of the radiolaria and some other skeletal remains) they are usually well rounded.

Littoral deposits consist chiefly of sand and pebbles, such as the well-known sea sand and shingle on the coasts. Recently deposited silt is found somewhat farther from the shore, but large littoral deposits of silt are found in the "warp" of the Humber, in the fens of Lincolnshire, Cambridge, and Huntingdon, in the flats and estuary of the Severn, in Morecambe Bay, in the reaches of the Solway, and elsewhere. They usually consist of grains of medium size, the smaller ones being largely separated by the flow of the tides, but littoral sands vary greatly in composition and physical properties. In some cases, the littoral deposits contain so much silt and clay as not to be rightly included in the term "sands."

Elevated marine sands are usually of a very fine silty nature, and may contain a large proportion of clay.

Marine deposits are usually wide and extensive. Their thickness varies according to the time during which the deposition took place, but in most cases, the deposits are remarkably uniform in thickness over large areas and are usually stratified. Marine sands usually consist of an irregular mixture of grains of many different sizes and of very variable composition, many different minerals being found. These sands are usually coarse, though some consist largely of very minute particles. (See also Chapter III., under *Sea Sands* and *Shore Sands*.)

Glacial Sands

Glacial deposits are closely related to those made by rivers, and are formed in a similar manner, but the materials composing

them are often much coarser, as the solid ice which forms the glacier is able to carry much larger fragments and even boulders. A characteristic feature of these deposits is the peculiar scratched surface of the boulders, which appear to have been dragged forcibly along in a direction parallel to the hill ranges and valleys in which they occur, or down which they have travelled. In some districts, *e.g.* the eastern counties of England, the Glacial Drift forms loose gravelly material consisting of fragments of all the older rocks from granite to chalk. In other localities, both in England and Scotland, large areas are covered by loose rubbly shingle and sand, forming mound-like ridges or flat-topped irregular mounds, as if the original gravelly deposits had been subsequently furrowed and worn away by currents of water. Deposits of glacial origin are often of large extent and are usually uniform in thickness and largely free from stratification.

The materials composing the great part of such deposits are gravel, quartz sand, limestone powder and clay, the two first-named being of more importance to the readers of this volume. The degree of admixture of these various materials depends chiefly on the composition of the rock or rocks from which the deposits were formed. Other glacial deposits consist of irregular aggregations of tough clay and sand with pebbles irregularly distributed through the beds. In some of these deposits, the clay is the predominant material, the sand occurring in lenticular "pockets" or irregular strata ; in other places, the sand and gravel predominate and the clay occurs in isolated masses.

The sands in glacial deposits partake of the mineral character of their respective districts ; thus, the glacial sand-beds derived from the Coalfields are usually dark-coloured and contain fragments of coal, shale, and other Carboniferous rocks ; sands derived from the Old and New Red Sandstone are usually red ; those from the Oolitic and Chalk tracts are yellowish or grey.

Glacial sands usually consist of well-rounded grains of various sizes, together with a very variable proportion of pebbles and gravel. The latter may be removed by screening, and any clay present may be separated by washing the sand. As glacial sands are very heterogeneous in character they are of limited usefulness.

Fluvio-glacial Sands

Fluvio-glacial deposits are those formed partly by glacial action and partly by the action of water derived from the melting ice. They are very similar in character to the continental river deposits found in mountainous districts and are slightly more regular than other glacial deposits, as they have been subjected to the sorting action of the water. The fluvio-glacial deposits in the valley of the Thames contain many different classes of material, including pebbles from the Bunter beds, sandstone, quartzite, tourmaline-breccia, quartz-schist, and rhyolite. The sand and gravel deposits

formed by fluvio-glacial action are sometimes so similar to fluviatile deposits that it is always difficult, and occasionally impossible, to distinguish them.

Sands formed by other Means

In addition to the sand deposits formed, as already mentioned, by the destruction of rocks and the subsequent re-collection and concentration of the particles by various natural processes, there are several other modes of formation which cannot be classified under those heads. The chief are :

(*a*) Sands formed by the accumulation of the remains of marine animals and plants.
(*b*) Sands produced by the precipitation of silica from solution, as the sandy incrustations around hot springs, etc.
(*c*) Sands produced by volcanic action, including tuffs, etc.

Sands produced by organic action may be of fresh-water or marine origin ; they consist of the skeletons or shells of minute aquatic animals and plants and of materials exuded by these creatures. The more important of such deposits are :

(1) Coral sands.
(2) Shell sands.
(3) Foraminiferal sands.
(4) Diatomaceous sands and earths.
(5) Globigerinal or radiolarian sands and muds.

Coral sands are produced usually by the disintegration of coral rocks by the action of waves, etc., the débris collecting into beds composed of particles of various sizes (p. 32). The coral rocks are, as is well known, the consolidated remains of calcareous coral organisms (Coralliaria) which have accumulated by the deposition of the remains of millions of such insects in warm salt water. After continued growth. coral rock acquires a structure like crystalline limestone. Much of the rock is disintegrated by the action of the waves upon it forming calcareous sand and mud which is carried away and re-deposited ; this remains sometimes as a loose sand, sometimes it is consolidated to form a secondary coral rock.

Shell sands are deposits of the calcareous shells of dead marine organisms. These are accumulated by marine currents, etc., and disintegrated to a greater or less degree, producing sands of varying fineness. Some shell sands consist of a heterogeneous mixture of grains of quartz and minute shells; others consist wholly of fragments of shells. In some cases, shell sands are raised above the sea-level and are carried away by the wind, forming dunes.

Foraminiferal, diatomaceous, globigerina, radiolaria and other similar sands are produced chiefly in the depths of the ocean by the accumulation of the minute skeletons and shells of calcareous and siliceous organisms. (See *Marine Sands*, p. 32; also Chapter III.).

Sands are sometimes produced by the accumulation of nodules formed by the segregation of calcareous matter from sea-water around some minute organisms, as in the case of "oolitic sands" (Chapter III.). Some plants, such as *Chara*, have the power of decomposing carbonates dissolved in water and precipitating calcium carbonate within their cell-walls. Others, including some mosses, form an incrustation on their exterior. Such deposits lead to the formation of various sinters similar to those caused by evaporation; later, these large accumulations of calcareous matter may be comminuted and again consolidated by the solvent action of water containing carbon dioxide in solution.

The "sands" produced by the precipitation or separation of substances from solution in springs, etc., may be mentioned, though they are not strictly sands. The principal deposits of this kind are (*a*) chloride deposits; (*b*) sulphate deposits; (*c*) borate deposits; (*d*) nitrate deposits; (*e*) carbonate deposits; and (*f*) siliceous deposits such as geyserite.

Volcanic sands are largely produced by the action of volcanoes which disrupt the rocks in their interior and throw out large quantities of small particles of volcanic dust which are carried by the wind and eventually fall on to the surface of the earth or into the sea. The size and density of the particles determines the distance to which they may be carried by the wind. The coarser particles usually fall in the immediate vicinity of the volcanoes, whilst the finest grains may be carried for hundreds of miles before they are deposited. Volcanic sands frequently contain a large proportion of crystalline matter, especially towards the close of a series of outbursts. Thus, showers of leucite and pyroxene have been ejected from Vesuvius, and pyroxenes coated with scoria are found on the flanks of Etna and Stromboli, whilst sanidine occurs in the ashes of Ischia, and much of the ash from Krakatoa consists of plagioclase, enstatite, augite, and magnetite.

Tuffs are classified by Pudson in three groups: (*a*) *vitric tuffs* containing a large proportion of glass dust; (*b*) *crystal tuffs* containing individual crystals; and (*c*) *lithric tuffs* containing fragments of rock, but no obviously glassy or crystalline particles.

CHAPTER II

THE OCCURRENCE AND DISTRIBUTION OF SANDS

Sands occur in almost all parts of the world, though they are distributed in a very irregular manner. They may, for convenience, be divided into two groups: (1) those being formed now or within recent times, and (2) those formed in previous ages and now forming part of the sedimentary strata of the country. The former are the topmost beds of the Post-Pliocene system and include superficial deposits formed by the recent disintegration of rocks and, in some cases, the transportation of the disintegrated material by wind, water, or ice to some other location. In short, they represent a continuation of the processes by which the older sands have been formed.

The second group includes sands which have been formed in the various ways described in previous pages, but have been subsequently covered by other materials and may also to some extent have been consolidated by pressure, or as a result of the infiltration of water containing cementing substances in solution. Where consolidation has occurred to any great extent, sand-rocks or sandstones are formed; some of these, as ganister rocks and quartzites, when crushed, are of value as sources of sand. Loose sands are chiefly confined to the more recent formations, as when they are deeply covered by rocks the pressure is usually sufficient to consolidate them, especially when other metamorphic influences are also at work.

In considering the distribution of sands it is convenient to arrange them in accordance with their geological sequence rather than their geographical position, as the latter is to some extent accidental. Primary sands—so far as any such sands are known—are taken first and the others, as far as possible, in the order of their deposition. Owing to earth-movements of various kinds, some local deposits of sand do not lie precisely in the position in which they might be expected to occur, but these small irregularities do not detract from the convenience of the geological arrangement.

TABLE IV.—ARRANGEMENT OF ROCKS AND ROCK SYSTEMS

Era or Period.		System.
Post-Tertiary		Post-Pliocene.
Cainozoic or Tertiary		Pliocene. Miocene. Oligocene. Eocene.
Mesozoic or Secondary		Cretaceous. Jurassic. Triassic.
Palaeozoic or Primary	Newer Palaeozoic or Deutozoic	Permian. Carboniferous. Devonian and Old Red Sandstone.
	Older Palaeozoic or Protozoic	Silurian. Ordovician. Cambrian.
Eozoic		Metamorphic. Archean.

ARCHEAN SYSTEM

Archean rocks only contain relatively small proportions of sand, and such material is usually so intermingled with the rock that it must be separated by washing, screening, or other mechanical means. Consequently, these rocks as a whole do not directly furnish much natural sand. They can only do so when the rock has undergone considerable disintegration, as part of the granite of Cornwall, Devonshire, and elsewhere from which china clay and kaolin are obtained, together with considerable quantities of sand. (See *China Clay Sands*, Chapter III.).

In addition to the small particles constituting such primary sands there are various igneous rocks, including pegmatites, aplites, micrograuites, and modified granites, which may be ground and so used as sources of sand which is very suitable for some purposes when the rocks are sufficiently free from iron compounds and other undesirable impurities. The cost of crushing is, however, in many cases prohibitive and the igneous rocks—being of a complex character—seldom produce sands of high quality. Some rocks which contain clastic felspar may, when crushed, be of value for glass-making, as, for example, granophyre from Brandy Gill, Cumberland.

The portions of igneous rocks composed of almost pure quartz are, unfortunately, generally useless on account of the great cost of grinding, sifting, and washing them. For many purposes also the crushed rock is not so suitable as the incoherent sand, so that, except in rare cases, crushed quartz is of very limited application.

METAMORPHIC SYSTEM

The metamorphic rocks, which lie immediately above the primary igneous rocks, consist of beds of clay which have been converted into schists and slates, and of sands which have been converted into quartzites. The distinction is not always clearly marked, and, in some cases, the hypogenic and epigenic changes which they have undergone are so great, and the proportions of added materials are so large, that it is now impossible to say which were originally strata of clay, which of sand, and which of gravel.

The *schists* and *slates*, being argillaceous in character, are outside the scope of this volume.

Mixtures of felspar, quartz, and mica may be converted into gneiss ; mica and quartz may form mica-schist, and the presence of talc or hornblende may give rise to talc- or hornblende-schists.

A **metamorphic quartzite** consists of a granular aggregate of quartz, derived from the quartz in primary igneous rocks by the action of pressure and heat, or of solutions of binding agents which permeate the interstices of the quartz. Such quartzites occur in various parts of the United Kingdom, including the Isle of Anglesey, Argyllshire, and West Inverness-shire. Quartzites belonging to the Highland metamorphic rocks occur to the north of Portaskaig and Port Ellen, Islay, Bonhaven Bay, Jura, Loch Leven, Appin, Duror, Glen Orchy, Dalmally, Loch Fyne in Argyllshire, and Inverness-shire, but up to the present they have not been used commercially.

Vein-quartz, associated with quartz-mica-schists, occurs at White Rock, north-west of Tinahely, Co. Wicklow, in a bed 100 yards long, 50 yards wide, and over 30 feet deep. It consists of pure white quartz, but at present it is not used. Similar deposits occur near Ynsyslas, Cardiganshire, and in various parts of the west and north of Ireland, Wales, and Scotland, though they are often irregular and impersistent. Vein-quartz also occurs at Slieve More, Achill Island, and is used chiefly in the manufacture of scouring and abrasive soaps. At Kildownet, in the south of the island, a micaceous quartzite has also been worked for the same purpose.

Metamorphic rocks form nearly the whole of the Outer Hebrides and occupy a belt of variable width in the west of Sutherlandshire and Ross-shire in Scotland, Donegal, Londonderry, Mayo, and Galway in Ireland, and they occur in irregular areas in Pembrokeshire, Anglesea, Carnarvon, and the Midlands. They consist of massive hornblendic gneiss with bands of schist, felsite, etc., but contain few rocks of any commercial importance as sources of sand. A quartzite which occurs on Holyhead Mountain, Anglesey, is crushed and used in the manufacture of silica bricks and also for furnace linings. When sufficiently finely ground it may be suitable for the manufacture of glass.

A sand resulting from the disintegration of a soft, white Dalradian

quartzite associated with some calcareous material, which occurs on the slopes of Muckish Mountain, some distance from Donegal (Ireland), is suitable for, and has been used for, the production of glass. As there is an abundance of sand, there is no need, at present, to crush the massive rock.

A similar deposit of Dalradian quartzite occurs at Port-a-cloy, Co. Mayo, and near Kentallen, Argyllshire. At the latter place, it is worked for sands for the filtration of acids and for grinding and refractory purposes. It has not been used for glass manufacture, though it appears to be suitable. At Stonefield, in Port-a-cloy Bay, Co. Mayo, sand obtained from a decomposed quartz-mica-schist is used for various purposes.

Much of the sand found on the shores of the Isle of Jura, Scotland, is derived from the disintegration of Dalradian quartzites, and has in the past been used for glass-making.

The beach-sands of the Isle of Eigg, which are also derived from metamorphic rocks, basalt, etc., consist largely of quartz, together with much kaolinised felspar and detrital minerals.

CAMBRIAN SYSTEM

The Cambrian rocks also include various quartzite rocks formed by the consolidation of deposited sands which might pay for crushing to sand. The chief of these are the Hartshill and Lickey quartzites, which occur in Warwickshire and Worcestershire respectively. The Hartshill quartzite extends from Nuneaton in a north-westerly direction, forming an outcrop a little over a quarter of a mile wide and nearly three miles long, and having a thickness, according to T. Eastwood, of about 900 ft. It consists of a white, pale pink or purplish, bedded rock with shaly partings dividing it up into the Upper or Camp Hill, Middle or Tuttle Hill, and Lower or Park Hill quartzites. It is worked at Hartshill near Atherstone, and at Nuneaton; it is crushed for use in the manufacture of silica bricks.

The Lickey quartzite occurs in the Lickey Hills, about 4 miles to the north-east of Bromsgrove and extending for nearly 2½ miles between Rubery and Barnt Green, with a width varying from 200 to 400 yards; it is worked at Rubery and Rednall. It is a hard, grey quartzite, slightly stained in some parts by iron, and is used chiefly for road-stone, but has been used as a substitute for ground ganister for furnace linings.

The quartzites of the Cambrian system in the Midlands are not so pure as some others, but when crushed they form useful sands.

ORDOVICIAN SYSTEM

The Ordovician system consists principally of sandstones and slates, and occurs in Central and West Wales, Co. Tipperary,

Ireland, and in Shropshire, but the only rock of importance as a source of sand is the Stiper Stones quartzite of Shropshire, which lies at the base of the Arenig series and crops out in a ridge between Snead and Pontesbury, the beds dipping steeply. This quartzite, which is worked at Nills Hill and Granham's Moor, near Habberley, consists of a fairly fine grey rock containing small pebbles and intersected by veins of vitreous quartz. It is ground and used as a sand in furnace hearths and linings, silica flour, and for filtration purposes.

SILURIAN SYSTEM

The Silurian system consists chiefly of mudstone, clay, and limestone, and contains no material of a sandy nature of commercial importance, though some impure sandstones and quartzites occur in it. The quartzite is largely the result of the metamorphism of pre-existing sand-rocks. Some of the Silurian sandstones in the United States are used for glass-making.

DEVONIAN AND OLD RED SANDSTONE SYSTEM.

The Devonian rocks, which occur exclusively in Devon and Cornwall, consist chiefly of sandstones, flagstones, and limestones.

The **Old Red Sandstone** occurs in Herefordshire, South Wales, and Scotland in the corresponding position to the Devonian rocks, but is an entirely different series, consisting of sandstones, conglomerate, marl, and beds of impure limestone. The Old Red Sandstone occurs chiefly in the Ochil and Sidlaw Hills, Moray, Caithness, and Ross, with a large belt skirting the Grampians from Stonehaven and the Firth of Tay to the Firth of Clyde, in Scotland, and in the hills of Hereford, Monmouth, and Brecknock (Wye and Severn valleys); the formation occurring in irregular patches from Wales to the north of Scotland.

A number of small, isolated areas occur at Sedbergh, Strickland in Westmorland, Haycot and Clun in Shropshire, and Presteign in Herefordshire, whilst much larger areas occur between Bridgnorth and Ludlow, practically the whole of Herefordshire and Monmouthshire, and the west of Worcestershire and Somerset, and from Abergavenny due south to Cardiff.

A siliceous conglomerate occurs in the Upper Old Red Sandstone near Fairlie, Ayrshire, but though it has been crushed so as to make a sand for silica brick manufacture, it is no longer used for that purpose. When Old Red Sandstone is weathered the chief material formed is a sand, together with some "marls," but most of the Old Red Sandstone rocks are of little value as a source of sand, the most useful being some of the quartz conglomerates found in Ayrshire and South Wales.

At Abercriban, near Merthyr Tydfil, the Grey Grit of the Old

Red Sandstone has formed a detritus of sand mixed with large and small blocks of grey sandstone occupying a large area and being in places more than 10 feet thick. This sand is used for lining open-hearth furnaces, for puddle, and as a substitute for ground ganister.

CARBONIFEROUS SYSTEM

The Carboniferous System is rich in sand rocks; it may be divided into six sections, namely: (1) Calciferous Sandstone; (2) Mountain Limestone; (3) Yoredale Rocks and Millstone Grit; (4) Lower Coal Measures; (5) Middle Coal Measures; and (6) Upper Coal Measures. The carboniferous rocks are widely distributed in the United Kingdom, the chief occurrences being in Central Scotland, Northern and Central England, Wales, and Ireland.

The Carboniferous System does not yield many deposits of loose sand, and is chiefly valuable for sand rocks such as sandstone, silica rock and ganister, which are ground to the desired fineness and then used for the manufacture of silica bricks, sand-lime bricks, and for furnace linings. They are, when crushed, also used for filtration and other purposes in the same way as sands. In many cases, however, the interstitial cement renders the material of little value. In other cases, it does not pay to crush the rocks owing to the proximity of other materials which need less preparation and can, therefore, be worked more cheaply.

The **Calciferous Sandstones** which occur in Fifeshire and Edinburghshire consist of hard siliceous sandstones which have been worked at Barnton, Currie Glen, and Craigleith quarries, in Edinburghshire, for use as building stone and for grinding glass, but they are too hard and too impure to be worth grinding so as to produce sand.

Hard quartzose rocks similar to ganister also occur at Kinghorn, Fifeshire, and probably extend inland on the same horizon. Soft and decomposed sandstones belonging to the Upper Calciferous Sandstone group occur at Coolkeeragh, north of Londonderry, where they are white or reddish in colour and are used for inferior bottle glass. A soft white sandstone about 30 ft. thick occurs in the Calciferous Sandstone Series near Lower Kildress, Cookstown, Co. Tyrone, the upper portion being stained brown or reddish and containing wedges of ferruginous matter. In the lower part is a thick bed of very fine sandstone, which is readily disintegrated on exposure and is used for glass-making.

Carboniferous Limestone.—The Mountain Limestone includes numerous pockets containing sand which has been left after the removal of the limestone in solution by water charged with carbon dioxide. The largest pockets or "swallow holes" occur in the Mountain Limestone of Derbyshire and North Staffordshire. In Derbyshire the pocket sands occur in an area enclosed by Monyash,

Youlegreave, Hartington, and Winster, and extending northwards to the junction of the limestone and shale beds.

At Park Mine, near Askham-in-Furness (Lancashire), sand, covered over thickly with boulder clay, occurs in pockets of haematite in the Carboniferous Limestone. It is used for moulding steel and for lining steel converters.

In Staffordshire useful deposits of sand occur near Oakmoor.

Other deposits are in Flintshire at Halkyn, Rhes-y-cae, Pantddu, etc., in Denbighshire, near Llandudno and Abergele, at Conway in Carnarvonshire, and in some parts of Ireland. The Abergele deposits are the only ones of much importance, the others being mostly small and not at present worked. The pockets are usually cup-shaped and contain pebbles, sand, and white or coloured clay, the materials being mixed to some extent with granular particles from the Millstone Grit rocks, which occur above the Mountain Limestone, and also with materials derived from other rocks as a result of glacial action. In some of the Derbyshire deposits, *débris* from the Bunter Sandstone, Pebble Beds, Keuper Marls, and Rhaetic formation are found, and in some places lignites occur, forming beds similar to those in which the Devonshire ball clays occur. (See also *Ganister Sands*, Chapter III.). Some of the pocket sands might be useful for glass manufacture, as at Brassington, Parsley Hay, and Abergele, but in most cases they are too irregular; they are used as refractory materials where they are sufficiently pure.

The principal silica rocks found in the Carboniferous Limestone Series are in North-eastern England, North Wales, and Scotland.

In *North-eastern England* there are several beds of siliceous rocks in the Carboniferous Limestone Series at various depths to nearly 1100 ft. below the Millstone Grit. The principal beds are: (1) the Egglestone silica rock or Romaldkirk ganister, which lies above the Fell Top Limestone; (2) the Harthope silica rock; (3) the Rookhope bastard and pencil ganisters; (4) the Fourstones silica rock below the Main Limestone; (5) the Nattrass Gill ganisters below the Undersett or Four-Fathom Limestone; (6) the Brigg Hazel rock above the Three-Yard Limestone; (7) the Lunedale rock between the Five-Yard Limestone and the Scar Limestone.

The Egglestone rock is worked at Castleside, near Consett, on an outcrop sloping slightly to the east under a covering consisting chiefly of shale. It consists of two beds of white and blue quartzitic sandstone respectively, and is used in the manufacture of silica bricks.

The Harthope silica rock outcrops from beneath a peat covering at Daddry Sheild, R.S.O., in Durham, and is employed for the manufacture of silica and ganister bricks.

The Rookhope ganister consists of a black pencil ganister and one of a lighter colour lying immediately above the Firestone Sill of the district, the top bed being the densest and most quartzitic, and is more suitable for use as a refractory material than the lower bed which passes into an ordinary sandstone.

The **Millstone Grit** is a typical, hard, quartzose sandstone, alternating with shales, which constitutes the lower beds of the Coal Measures and so is known to colliers as the " Farewell Rock." Where it is not so covered, it usually forms narrow areas immediately around the great coalfields of Wales, Yorkshire, Derbyshire, the west of England and on the edge of the Northumberland and Durham coalfield, though some small areas of it are distributed irregularly some distance away. Thus, to the south of Hexham and Haltwhistle in Northumberland are several such isolated areas, whilst numerous others occur to the north-east of Sedbergh. A large area of Millstone Grit extends from Lancaster to Settle and Garstang. Another large tract occurs in West Devon, extending from Barnstaple to Tavistock and from Bampton to the Bristol Channel.

The Millstone Grit rocks vary in thickness in different parts of the country. In the Mendip Hills, near Bristol, they attain a thickness of from 500-1000 ft. In central England, the rock is lighter in colour and contains many pebbles of white quartz, passing sometimes into a conglomerate, and at other times abounds in grains of felspar, forming an arkose rock. It is thickest in South Lancashire and Yorkshire, but to the north, in Northumberland, it decreases to about 400 ft. in thickness, and is even thinner in Scotland.

In *Cumberland* a coarse yellowish-white, felspathic and slightly micaceous sandstone occurs near High Harrington in association with mixed shales ; it is ground and used as a substitute for ganister and ganister sand.

In *Derbyshire* a bastard ganister occurs in the Millstone Grit Series about 12 ft. below the base of the Rough Rock at Ridgeway, Ambergate, and a silica rock termed " Litchfield's Ganister " occurs some distance below this in the same formation, but these deposits have not been, as yet, sufficiently well investigated to determine their uses. The waste material, left after preparing large blocks for building purposes, from the Millstone Grit rocks at Rowsley may be used for making common glass.

In *Yorkshire* the Millstone Grit at Bentham is crushed for pig-bed sand.

In *North Wales* the principal Millstone Grit rock of commercial value is the Cefn-y-fedw sandstone, which occurs in isolated areas near Mold and Minera and between Trevor and Porthywaen.

In Flintshire it is worked to the south-west of Mold as a source of silica sand for pottery manufacture. Another exposure in the same district is ground and sold as silica flour. At Graianrhyd the sandstone, which is about 60 ft. thick, is used as a source of silica sand and for refractory purposes and for scouring and abrasive soaps ; near Buckley it is ground and used as a sand for lining open-hearth furnaces.

In Denbighshire the upper part of the Cefn-y-fedw sandstone consists of a highly felspathic grit, whilst in Flintshire it consists

largely of pebbly sandstones and grits. The best portions of the bed consist of a quartzose sandstone with or without pebbles and containing very little felspar. Such beds occur at Ffrith, Bwlchgwyn, Minera, and near Trevor, and are used for the manufacture of silica bricks, as a source of sand for filter beds, for dressing furnaces, and also for the manufacture of abrasive soaps.

In *South Wales* there are large deposits of siliceous rocks, the whole of the material used in the manufacture of silica bricks being obtained from the Millstone Grit rocks which outcrop around the edge of the South Wales coalfield, between the Limestone and the overlying Coal Measures, and pass under the Bay of Swansea and Carmarthen. The outcrop appears almost continuously for a distance of nearly 140 miles from Monmouthshire through Brecknockshire, Glamorganshire, and Carmarthenshire, and from the western side of Carmarthen Bay into Pembrokeshire. The rocks are not available over the whole length of the outcrop as they are partially covered by the Triassic rocks, especially near Cardiff. Along the northern margin of the coalfield the Grit is well developed, the dip of the beds being much less than to the south and in Pembrokeshire, so that the outcrop is much wider. At the northern margin the beds may be divided into three distinct strata :

Farewell Rock	0-450	ft. thick.
Shale	100-1000	,,
Basal Grit	0-700	,,

On the north-eastern and south-eastern sides the various beds are less clearly defined and more shaly than to the north. To the south the formation consists of shales, conglomerates, grits, and sandstones of great thickness, but apparently small commercial value.

The Basal Grit supplies the whole of the materials at present used for silica bricks in the area, though there are ample resources in the overlying beds.

All three beds are chiefly composed of quartz pebbles and grains of various sizes. They vary from hard quartzites to soft conglomerates or sandstones. The harder varieties are chiefly used for silica bricks, whilst the softer materials are worked for hearth sands, ganister mixtures, silica cement, moulding sands, and for composition and paints used in foundry work. The principal districts where these beds are worked include Dowlais, near Merthyr Tydfil ; Penderyn, the Vale of Neath, and Penwyllt, near Neath ; the Black Mountain and the Vale of Tawe and Brynamman, near Swansea ; Llandybie, near Llandeilo ; Mynydd-y-gareg, near Kidwelly ; and Templeton, near Narberth.

At Clydach, near Abergavenny, the basal bed of the Millstone Grit has been suggested as suitable for the production of ground silica for lining open-hearth furnaces.

The Millstone Grit in this area is much weathered in places,

forming a loose sand which is used for the same purposes as the solid rock, but has the advantage that it needs little or no crushing. Weathered beds of this kind occur at Hirwaun, near Aberdare, and Penwyllt in Brecknockshire, Mynydd-y-gareg, near Kidwelly, Brynamman and Upper Cwmtwrch in Carmarthenshire, and in the Vale of Neath in Glamorganshire.

The Basal Grit at Mynydd-y-gareg has been crushed very fine and used as a polishing powder to some extent. Some of the soft sandstone at the base of the Millstone Grit around Carmarthen has been dug for building sand. South of Castle-Côch, yellow loamy sands with bands of fine and coarse gravel to a depth of 32 ft. have been worked for building sand. The lower layer, which is about 7 ft. thick, is best suited for this purpose.

In *Durham* the beds of Millstone Grit yield various fine-grained quartzose sandstones, some approaching bastard ganisters, which are used for the manufacture of silica bricks and as sources of sands for furnace linings, etc. The Grit is conveniently divided into three groups, the two upper ones yielding four beds of serviceable stone. In the topmost beds are the silica rocks of Castle Hill, near Consett, and those of Cross Quarry, near Stanhope, whilst in the middle beds are the rocks of West Butsfield Quarries, Consett, Sandy Carr, near Redgate, and Weatherhill Quarry, near Spennymoor.

In *Central Scotland* there are two important beds of siliceous rock lying respectively one above and the other below the Middle Fireclay in the Millstone Grit. In some places, there are several beds of ganister interstratified with fireclay, whilst in others only one bed occurs between thick beds of fireclay. At Bonnybridge (Bonnyside and Dykehead pits) both ganister beds are worked, the upper being the most valuable, but at Drum Mine and Greenhill only one bed occurs.

In Linlithgowshire, a white medium-grained sandstone occurring above the Top Fireclay is used for silica bricks. At Blochairn, near Glasgow, two beds of white sandstone occurring in the upper part of the Millstone Grit are worked. The upper bed is about 20 ft. thick, and consists of a hard white siliceous rock which was at one time ground for use in open-hearth furnaces. The lower bed is more argillaceous, and is suitable for moulding sand. At present neither of these beds are in use. These beds belong to those termed " rotten rocks," which are worked in the Millstone Grit at Drumcavil, Garngad Road, Garnkirk, and Glenboig, chiefly for moulding sands, but also for furnace hearths and for making silica bricks.

In Stirlingshire, a white ganister occurs about 60 ft. below the Lower Fireclay at Castlecary ; it is crushed and used for silica bricks. At Gartverrie, near Glenboig, a sandstone occurs 90-120 ft. below the Lower Fireclay ; part of this bed is used for the hearths of open-hearth furnaces and as a moulding sand. Some has also been used for glass manufacture. At Levenseat (Edinburghshire), a soft decomposed sandstone occurs over shale beds in the lower

part of the Millstone Grit formation, and is covered in places by a thin layer of Glacial Drift. It is ground and used for inferior glass-ware, and may also be used in metallurgical furnaces.

Siliceous sandstones also occur in the Millstone Grit at Kello Water, Dumfriesshire.

In *Ireland* the Ballycastle sand lies on the Carboniferous sandstone, and may have been partly derived by the disintegration of this bed, and has been added to by blown sand from the dunes. The material is used for the manufacture of bottle glass.

The **Lower Coal Measures** consist chiefly of argillaceous shales, sandstones, coals, and grits, or of white sandstones and dark oily shales (as in the Scottish Lothians). They are apparently of fluviatile or lacustrine formation, though there is occasional evidence of marine deposits and of admixture with igneous rocks which have been brought to them by the action of flowing water. The sandstones may be very coarse and loose, or fine and compact, as in *ganister* (see Chapter III.).

Ganister and ganister-like sandstones occur in North Lancashire, Derbyshire, Durham, and South Yorkshire. The most important deposits of true ganister are found around Sheffield and in other parts of South Yorkshire; they lie between Halifax Hard Mine Coal and the top of the Millstone Grit; the best beds being immediately below this coal and bearing the name Hard Mine Ganister; they vary in thickness from a few inches to more than 5 ft. A bastard ganister which occurs beneath the Clay Coal in some localities very closely resembles the Hard Mine Ganister.

The Hard Mine Ganister is chiefly obtained near Beeley Wood and Deepcar and in the Little Don Valley between Stocksbridge and Huddersfield. A bastard ganister occurs in places below the Hard Bed Band Coal and is worked at Bullhouse. These deposits are chiefly used for the manufacture of silica bricks, silica cement, and ground ganister for furnace work. The beds dip steeply, and whilst they outcrop at Totley on one side of Sheffield, they occur at a depth of nearly 400 yards at Deepcar on the other side.

In the Huddersfield, Halifax, and Leeds districts the Hard Mine Ganister occurs, sometimes as a ganister and also as a siliceous clay and a siliceous sandstone.

At the base of the Lower Coal Measures very pure and much-shattered Carboniferous sandstone, called the "Guiseley rock," is worked near Guiseley (Yorks.). It is crushed and used in the steel industry, and has also been employed on a small scale for glass-making.

In *Derbyshire* the Sheffield ganister occurs around Beauchief, Dore, Totley, and Bullbridge near Ambergate, in the same horizon as in South Yorkshire. To the south-west of Chesterfield a ganister occurs above the Alton Coal, and at Ridgeway, near Ambergate, a bed termed "Glossop's ganister," which occurs about 100 ft. below the Alton Coal, is more correctly regarded as silica rock than as a true ganister.

In *Durham* two important beds of silica rock occur in the ıower Coal Measures. The upper bed occurs at Crook and Knitsley 'ell, south of Wolsingham. The beds dip slightly to the north, ınd consist of fine-grained sandstones which are used for the manufacture of silica bricks. The lower bed occurs just above the Millstone Grit at several places around Crook and to the south of Wolsingham. In some places it is a true pencil ganister. Selected portions are used for the manufacture of silica bricks and for pug ganister.

In *North Lancashire* a poor quality of ganister lies below the Lower Mountain Mine Coal, which is equivalent to the Alton Coal of Yorkshire. It is used for the same purposes as ganister. The Warmden rock, which lies above the Inch Mine Coal and is worked in the Accrington district, may be useful for silica bricks, and when ground forms a substitute for ganister. Some of the siliceous sandstones of the Millstone Grit in Lancashire and Cheshire are crushed for moulding sand and sand for forge furnaces.

In *Scotland* two siliceous sandstones occur above the Lime Coal at Byreburn (Dumfriesshire) and appear to be suitable for silica bricks, furnace hearths, and possibly for glass manufacture.

In *Ireland* a soft cream-coloured sandstone about 60 ft. thick occurs in the Lower Carboniferous Sandstone Series above the Main Coal of the Ballycastle coalfield. The lower portion is easily crushed, and is used for furnace linings and for glass-making. The upper portion of the beds contains shale bands and is, therefore, of lesser value.

The **Middle Coal Measures** consist of grey shales and sandstones with seams of coal, fireclay, and ironstone. The greatest thickness is in North Staffordshire. Some of the sandstones are red.

The silica rocks and sandstones in these measures occur in Cumberland, Derbyshire, Shropshire, and Gornal in South Staffordshire.

In *Cumberland* there are no true ganisters, but several silica rocks occur in association with the Clifton Little Main Coal at Branthwaite, and Flimby. At Branthwaite the beds crop out from beneath the overlying glacial deposits, whilst at Flimby they lie beneath a bed of 4 ft. of fireclay which occurs immediately under the Little Main Coal. At Workington the ganister occurs beneath the underclay of the fireclay coal, which is about 50 ft. below the Little Main bed. These silica rocks are chiefly used for silica bricks and as a substitute for ganister.

In *Derbyshire* the silica rocks in the Middle Coal Measures are worked at Riddings, to the north of Ambergate, where they occur as a fine-grained quartzite above the Tapton Furnace or Low Main Coal, and are used, together with Derbyshire "ganister sand," for the manufacture of silica bricks.

In *Shropshire* the Ketley sandstone in the Middle Coal Measures is associated with the Fungous Coal at Ketley, where it is used for silica bricks and as sand for reheating furnaces.

In *South Staffordshire* is a white or yellowish stone, known locally as "Gornal stone," which is worked at Upper Gornal, near Dudley. The stone is ground and used for "cupola sand." The finest grades are sold as "best white sand" for gasworks and for use as scouring sand. At the base of the Gornal stone is a so-called ganister, which is ground and used for wall-plastering and for lining blast furnaces.

The **Upper Coal Measures** are composed of sandstones, fireclays, and bituminous shales, and seams of ironstone, coal, and limestone frequently occur in them. They are best developed in the Bristol and Somerset coalfield, but they also occur in the Midlands. No sands or sand rocks of any commercial importance occur in the formation.

PERMIAN SYSTEM

The Permian System consists of red sandstones, marl, magnesian limestone, and yellow sands. Their distribution is not well defined, except in North and Central England, East Durham, Central Yorkshire, Nottingham, and Shrewsbury, where the formation runs in an almost straight line from Tynemouth to Nottingham and the magnesian limestone is prominent.

The Permian Sandstones are very irregularly distributed. They consist chiefly of reddish sandstone, of mottled, purple, yellow, green, and brown shales. The magnesian limestone yields calcareous flagstones. The lowest Permian beds consist of a very variable series of sandstones, sands, and clays of various colours, irregular thickness, and great diversity of character. The Lower Permian yellow sands are often quite incoherent, but are frequently too deeply iron-stained and calcareous along their outcrops to be of much value, though they may be used for some purposes.

A somewhat important area occurs in South Cumberland, and extends from Wreay to Penrith, Appleby, and Kirkby Stephen. A narrow strip runs irregularly along the eastern edge of the Durham coalfield from South Shields to Shincliffe. A small area occurs near Thornton in Yorkshire, another near Clitheroe, and various irregular strips near Leigh (Lancs.) and north and east of Manchester, extending through Stockport to the Macclesfield Canal.

In North Derbyshire the quicksands at the base of the Permian beds—which are about 20 ft. thick—are used for building sand from pits at Barlborough and Pebley Pond. At Red Hill and Cresswell the sandy beds of the Middle Permian marl have been tried. At Barlborough the sand is sufficiently cohesive to be tunnelled from beneath the overlying clays and to stand firmly in the roofs and walls of old workings.

The base of the Permian beds, from Clowne towards the Yorkshire border, consists of semi-incoherent sands, which replace the breccia in the corresponding position farther south. These sands

consist chiefly of rather fine-grained quartz sand of a pale yellow colour, sometimes orange and red in patches, and having the consistency of a soft sand rock which is easily crushed; in places they are indurated with calcite, and occasionally studded with rusty brown pellets about $\frac{1}{4}$ in. in diameter and cemented by iron oxide. The beds, which are variable in thickness and often cross-bedded, are much obscured by overlying clays.

Numerous and irregular small areas occur in Shropshire, notably (1) around Shrewsbury, (2) north of Oswestry to Gresford, (3) south of Newport to near Kidderminster, and (4) east of Market Drayton. Similar irregularly shaped areas lie around the South Staffordshire coalfield, particularly between Shareshill, Wolverhampton, Stourbridge, Lickey Hill, and West Bromwich. A relatively large area extends from Kenilworth to near Atherstone, with unimportant outliers to the north and west.

The southernmost area of Permian sandstone extends irregularly from Nether Stowey in Somerset, through Tiverton and Exeter to Torquay, with a westward branch from Silverton to Exbourne.

TRIASSIC SYSTEM

The Triassic system was at one time included, together with the Permian system, under the general title of "New Red Sandstone," but is better considered separately. The Trias beds of Great Britain may be divided into three distinct sections as in Table V.

TABLE V.—TRIASSIC SYSTEM

1. Rhaetic	Shales and limestone.
2. Upper Trias or Keuper	New Red marls and waterstones.
3. Bunter Sandstone	Upper Mottled Sandstone, Middle Pebble bed, and Lower Mottled Sandstone.

Both the Bunter and Keuper series indicate sea and desert conditions, with much wind-drifted material. The Trias marls were probably formed by a fine dust borne from some arid district and deposited in a salt lake, forming marl beds with layers of gypsum in between.

The **Rhaetic Beds** follow the upper limit of the Keuper beds (*i.e.* between Trias and Lias). They comprise grey marls, black shales, and White Lias limestone, and are most developed east of Taunton and in the Polden Hills at Sedgemoor. The Somersetshire Rhaetic beds, formed of black shales and White Lias limestone, lie under the Lower or Blue Lias, which is extensively quarried for stone, lime, and cement. They consist of thin-bedded shales, clays, and sandstones.

A greenish-grey Rhaetic sandstone which occurs at Morriston (Glam.) is worked as a material for silica bricks and furnace linings.

The **Keuper Beds** consist of clays with thin layers of sandstone,

veins and nodules of gypsum, and impersistent beds of rock salt. They are chiefly found in Cheshire, but also occur in the Solway basin and down towards the Mersey, where they merge into " that broad belt of red sediments which stretches diagonally across the whole country from Durham to South Devon."

The *Keuper Waterstones* consist chiefly of soft sandstones, which around Higher Bebington, Cheshire, are 30-40 ft. thick, and are crushed for use as refractory materials in the iron, steel and copper industries and also for bottle glass. The chief disadvantage of this material is the clayey substance in it. At Alderley Edge, Cheshire, are large tips of sand, derived from the Keuper waterstones which have been worked for copper and lead. It might be suitable as a sand for bottle glass, though it is remote from glass-making areas.

The Keuper waterstones in Derbyshire are thin, red and greyish flags interstratified with red marls. They form a flaggy, sandy base to the lower part of the Keuper marls and are only a few feet thick.

The Keuper beds extend, with some interruptions, across the country from Axmouth and Sidmouth to the mouth of the Tees, forming valleys in the south and west of England, the Vale of Taunton, and to the east of the Malvern range. The beds extend over the eastern half of Nottinghamshire, the west of Lincolnshire, and reach into Derbyshire and Staffordshire.

The uppermost portion of the Keuper beds is widely distributed ; it can be traced from the coast of Lancashire to the Bristol Channel, and covers a larger area in the Midlands than the rest of the Trias and the whole of the Permian Sandstones combined. It also occurs at Budleigh Salterton in the south of Devonshire.

Keuper beds also occur in patches along the west coast of Scotland and along the east coast of Ireland. Pebbly sands occur near their base in the neighbourhood of Belfast.

The **Bunter** or **Lower Trias** is usually divisible into the Upper Mottled Sandstone, a middle bed of conglomerate, and a lower bed of Mottled Sandstone. One large tract of this formation extends from Annan in Scotland to Longtown and Brampton, thence southwards to Brough in Westmorland. This formation also extends along the coast from St. Bees to Morecambe Bay, West Hartlepool, and Darlington, across the Tees to Northallerton and somewhat south of Ripon, where it is divided by more recent deposits, but covers an area west and south of York and, in an irregular manner, the districts west of Selby and Snaith.

Between Thorne, Doncaster, and Bawtry, and southwards to Nottingham, the Triassic area is broad and important, Retford forming its most eastern boundary and Mansfield its most western one. The Triassic areas in Derbyshire and Staffordshire are irregular—a small one at Morley and another extending from Repton-on-Trent through Church Gresley to Nether Seal in Leicestershire.

The banks of the river Trent present many good sections of these strata, as at the junction of the rivers Trent and Soar, where they are pierced by the Red Hill tunnel on the Midland Railway; and at Radcliff-on-Trent, where they form picturesque cliffs of a red colour. The strata are also exposed to view in many places in the vicinity of Nottingham, as in the cutting for the old road over Ruddington Hill, in the Colwick cutting of the Nottingham and Lincoln Railway, and Goose Wong Road, leading to Mapperly Plains.

A larger area of Bunter Sandstone extends from Keddleston to Ashbourne, others around Longton, Whitmore, and Leek being equally significant.

The Triassic area west of the Potteries coalfield, though nominally in Staffordshire, is really a portion of the large area extending across the northern half of Shropshire, southwards to Quatford and northwards to the borders of Cheshire.

A large area of the Lower Trias extends from the Mersey (New Brighton and Warrington) through Chester to Ellesmere in Flintshire. A branch of this lies between Rhyddlan and Ruthin. A much-extended and irregular area reaches along the west of Lancashire from Cockerham through Preston and Ormskirk to Liverpool, east to Warrington and Manchester, and south to Macclesfield. A large area extends from Stafford to Wolverhampton, Stourbridge, and Stourport, and another from Lichfield to Birmingham, with a small district around Lickey Hill between these two areas.

The three divisions of the Bunter beds do not persist throughout the whole of the areas mentioned, but in places are very thin or wholly absent, whilst other portions may be well developed.

The Bunter pebble beds are light yellow, coarse-grained sandstones with scattered, well-rounded pebbles of quartz or other rocks. In places they change to a light-coloured grey sandstone, with bands and lenticles of conglomerate and occasionally a few pebbles. The stone rarely has a reddish tinge and sometimes has a mottled appearance on the weathered surface.

The Lower Mottled Sandstone consists of bright red or crimson sandstones blotched with brown or yellow patches and free from rounded pebbles. In places it varies from smooth well-bonded red deposits to a coarser and paler red material which gradually changes into the Bunter pebble beds. The beds are impersistent along the southern edge of the Notts and Derby coalfield and contain lenticles of breccia and thin partings of red marl. It is frequently absent. In Derbyshire it is just over 100 ft. thick, the upper bed consisting of fine-grained red sandstone containing some clay or marl. The lower beds are more marly, and at the base thin lenticles of red marl alternate with soft fine-grained materials. The yellow mottling is rarely present here, but is seen at Nottingham.

The Bunter beds yield various valuable commercial sands, particularly moulding sands, which are worked in many parts of

the area in which Bunter sands are available, but especially in the Potteries, Nottinghamshire, and Yorkshire.

Upper Bunter sands are worked for moulding sands at Birmingham Cemetery, where the face is 70-80 ft. thick, being capped by only a very small amount of inferior sand which is used for building purposes. These beds are also worked between Stourbridge and Wolverhampton and in Worcestershire, near Kidderminster and Stourport, for red moulding sand. Other Upper Bunter sands are largely used for building purposes.

Some of the Bunter pebble beds have been used for building sand and the pebbly bands have been screened for gravel. At Bawtry in Yorkshire they have been used for making silica bricks, the material being carefully picked before use.

Lower Bunter sands in Yorkshire are worked for moulding sand at Armthorpe, Bawtry, Burghwallis, Doncaster, Heck, Hensall, Snaith, and Whiteley Bridge. At the four last-mentioned places around Selby the sands occur beneath the glacial beds. In Nottinghamshire they are worked at Hempshill, Lenton, Mansfield, Nottingham, Sutton Junction, and Worksop. The Mansfield and Worksop deposits are amongst the most famous in the country. At Mansfield the beds are 60-70 ft. thick, the upper 30 ft. or more being used as pig-bed sand, whilst the lower 16-30 ft. consists of a soft brick-red sand which is well known as the Mansfield moulding sand. At Worksop the beds are 20-35 ft. thick, the bulk being used as moulding sands; but some of the lower parts are very pure and are used for glass-making, and are also used for the hearths of open-hearth furnaces. Some of the inferior Worksop sand is used in the building industry.

In Lancashire the Lower Bunter beds are worked as moulding sand at Ormskirk, where they are 70-80 ft. thick, and in Cheshire they are worked at Runcorn from beneath the boulder clay, the deep-red sand obtained being used chiefly as a pig-bed sand.

In Staffordshire, Lower Bunter beds are worked at Wolverhampton, where they are especially fine, and are used largely for brass casting, and at Compton and Wombourne. Some of the South Staffordshire beds have also been used as a siliceous ingredient of firebricks.

Bunter moulding sands are also worked in beds about 30 ft. thick between sandstones at How Mill in Cumberland.

The famous Belfast sands are of Bunter Age and are worked at various places in the vicinity of Belfast for moulding purposes.

JURASSIC SYSTEM

The Jurassic system includes the Lias and Oolite formations, the former being of marine origin and the latter mainly lacustrine or estuarine. It includes a great variety of limestones, sandstones, marls, shales, and clays lying between the New Red Sandstone

and the Chalk, the Lias forming the lowest group and the Purbeck beds the uppermost one. In Great Britain the Jurassic rocks may be classified as shown in Table VI.

TABLE VI.—JURASSIC SYSTEM

OOLITE	*Upper Oolite.*—Estuar[illegible] with sands and clays (*Purbeck Beds*) [illegible] Wealden; coarse and fine-grained oolitic limestones, with layers of calcareous sand and concretions (*Portland Stone* and *Shotover Sand*); dark laminated clays, with gypsum and bituminous shale (*K[illegible] Clay*).
	[illegible] Coarse-grained, shelly, and coralline oolite, with calcareous sands and grit (*Corallian Rocks*); dark-blue clays, with subordinate clayey limestones and bituminous shale (*Oxford Clay*); shelly calcareous grit (*Kellaways Rock*), with subjacent blue clays.
	Lower Oolite.—Coarse, rubbly, and shelly limestones (*Cornbrash*); laminated shelly limestones and grits (*Forest Marble*); sandy layers and thick-bedded blue clay (*Bradford Clay*); thick-bedded oolite, more or less compact or sandy (*Great Oolite*); flaggy grits and oolites (*S[illegible]e*); marls and clays, with soft marly limestone [illegible]; calcareous freestone irregularly oolitic, and yellow sand (*Inferior Oolite*).
LIAS	*Upper Lias.*—Thick beds of dark bituminous shale; beds of pyritous clay and alum shale; indurated marls or marlstone with beds of ironstone.
	Middle Lias.—Sands, shales, and brick earths overlain with limestone.
	Lower Lias.—Dark laminated limestones and clays; bands of ironstone; layers of jet and lignite; beds of calcareous sandstone.

THE LIAS

The Lias rocks consist chiefly of alternating layers of shales and limestones extending from the Tees *via* the Cotswolds to Lyme Regis.

The formation extends along the Yorkshire coast from Robin Hood's Bay to the mouth of the Tees (Redear), then south-west to Northallerton, and south-east *via* Thirsk and Pocklington across the Humber, and due south through Lincolnshire and East Nottinghamshire into Leicestershire. In the last-named county the area is much broader—the width being greatest from Leicester to Hambleton in Rutlandshire, but it narrows again on entering Northamptonshire and Warwickshire, and is then much broken up by Trias or obscured by overlying Oolite.

From Warwickshire the Lias extends south *via* Banbury to Bletchington, and south-west through Cheltenham and Gloucestershire to Bath and Bristol. It narrows down near Dursley, where it runs due south into Somersetshire, though in the last-named county it is often rendered inaccessible by alluvium. Here it spreads into numerous isolated areas, but unites again at Glastonbury, and extends to the Dorset coast near Bridport and Lyme Regis.

Isolated areas of Lias (usually limestone) occur in several

districts; one of the largest extends from Audlem to near Wem (Shropshire), and another, rather smaller, occupies the Welsh coast from St. Brides to near Cardiff.

The Lias of the North of Scotland consists in some parts of dark-coloured unctuous clays, in others of greyish black sandstone so fine as to resemble an indurated clay, or of beds of black fissile shale alternating with bands of coarse, impure limestone and studded with limestone nodules. These deposits are of little importance so far as sand and sand rocks are concerned, there being only a few beds of a sandy nature of little practical value.

The **Middle Lias** is mainly composed of sand and shales overlain with limestone, and around Frome the Lias contains a variety of brick earths, sands, etc., but the sand in these beds is seldom used separately, as it cannot be separated on a large scale at a commercially profitable rate.

The Oolite

The Oolitic Rocks consist of limestone, grits, conglomerates, sands, and clays (often limey), and form a broad belt above the Lias from Dorset into Yorkshire. They are stratified as shown on p. 56.

The **Purbeck Beds** consist chiefly of shelly limestone, clays, and shales, with occasional sandy layers. These appear in various places between Swanage and St. Alban's Head. The Purbeck strata outcrop alongside the Portland beds in Dorset, in the Vale of Wardour in Wiltshire, at Swindon, and on to Aylesbury. They lie immediately below the Wealden deposits. The Hastings sands appear immediately above them.

The **Portland Beds** consist of a series of sands, sometimes glauconitic, and concretionary sandstones and clays, succeeded by massive oolites and freestones, with chert and occasional beds of clay. Unfortunately, the purer sands in these deposits occur in relatively thin beds, much overlain by other deposits of small commercial value.

This formation extends from Durleston Head to St. Albans' Head and forms most of the Isle of Portland. It also occurs near Weymouth. In the Vale of Wardour, in Wiltshire, and continuing towards Oxford and Aylesbury, the beds consist chiefly of calcareous sandstone. At Shotover in Oxfordshire the beds are about 60 ft. thick and form large blocks of concretionary sandstone. The Portland beds are usually rather impure, and generally of a grey or brown colour. Below the Portland beds and above the Kimmeridge clays are the Shotover sands, which are not of any particular commercial value on account of the large proportion of lime and iron compounds in them.

The **Kimmeridge Clay** contains no sand beds of much commercial value.

The **Corallian Rag** consists largely of marine oolitic limestones,

marls, Coral Rag, calcareous sandstones, and sands which extend from Weymouth to Oxford, where it changes to a clay and continues northwards into Yorkshire, where the sandstones are again developed. Beyond Aldeburgh the upper part of the Red Corallian Rag passes into a shelly sand and gravel which extends between Dunwich and Northwich and Weybourne.

A greyish-white, partially decomposed sandstone belonging to the Corallian beds occurs in association with coal and oil shale at Brora (Scotland) and is suitable for refractory purposes, though the problem of transportation is difficult. The Corallian sands are chiefly clayey and calcareous, and are of inferior quality.

The **Oxford Clay** consists chiefly of stiff clays and shales, but at the base of this formation are shelly sandstones, sands, and loams comprising the **Kellaways beds,** which extend from Weymouth through Wiltshire to Bedfordshire, Lincolnshire, and Yorkshire, and also at Uig in the Isle of Skye. Near Bedford and in Lincolnshire the sandy Kellaways beds are well developed. The sands in the formation are very irregular and were apparently laid down in comparatively shallow water, in contradistinction to the clays, which are of deep-water origin.

At Burythorpe, near Malton (Yorks.), the Kellaways beds consist of cream or pale-brown sands 8-10 ft. thick, and very similar to those of the Inferior Oolite. The best qualities are suitable for bottle glass, and after some purification they may be used for glass of better quality. Similar, though less valuable, deposits occur in the same formation at South Cave and Newbald. At South Cave, Estuarine sands occur, and the two beds are mixed and used for moulding sand.

The **Lower Oolite** extends from Saltburn, on the Yorkshire coast, over the York moors and southwards to Acklam. After a gap of some twenty miles a fresh area occurs at Newbald, near Beverley, and continues directly southwards across the Humber through Lincolnshire (Sleaford being its most easterly point in this county), through the east of Rutlandshire to Peterborough and south-east through Northamptonshire (where it is much broken up by Lias) and skirting Oundle and Thrapston in Huntingdonshire. This formation also extends across North Oxfordshire, the east and south-east of Gloucestershire, north-west Wiltshire to Bath and the Cotswold Hills, and southwards through east Somersetshire to the Dorset coast at Burton Bradstock. The sands in this formation are for the most part too calcareous to be of much value as a commercial material.

The Upper beds of the Lower Oolite series, including the **Cornbrash** and **Forest Marble,** consist chiefly of limestones with occasional beds of clay and sand. The beds crop out from Templecombe by Wincanton to Frome; at Charterhouse Hinton sands with white masses of hard sandstone occur. Sandy beds also occur in the Forest Marble of Wiltshire at Carsham and Malmesbury. In some parts of Dorsetshire the Forest Marble passes into multi-

coloured clays and sands. Most of the sands of these upper beds are of small commercial value.

The **Great Oolite,** which lies below the Forest Marble, comprises an Upper Estuarine series of coloured clays, sands, shelly limestones and calcareous clays, but it is very irregular. It crops out alongside the Forest Marble from Templecombe by Wincanton to Frome.

Various sand beds occur in the Upper Estuarine Series in Oxfordshire and in the Great Oolite Clay, which series extends through Bedfordshire and Northamptonshire into Lincolnshire and Yorkshire.

The most important of these are the *Northampton Sands,* which consist of a series of sandy and ferruginous beds with some calcareous bands rarely more than 100 ft. thick. In the lower part of these sands the Northamptonshire iron ore occurs. It is a hard, dark-greenish-grey iron carbonate with grains of quartz and oolitic grains, the whole weathering into the brown ferric hydroxide (limonite).

At Denford, Corby, Warsford, Apethorpe, Blatherwyke, etc. (in Northamptonshire) the Estuarine sands are worked for use in steel works and, to a small extent, for glass manufacture. Similar sands of inferior quality occur at Tadmorton, near Banbury, where the beds, 16 ft. thick, are associated with peat.

At Huttons Ambo, near Malton (Yorks.), the Upper Estuarine beds consist of grey and yellow sands, with grey calcareous layers. They are used for steel casting. The lower beds are much purer than the upper ones, and may also be used for the best qualities of glass, including optical glass, and for the hearths of open-hearth furnaces. At Sancton the sands are white, but very micaceous.

As a general rule the Estuarine sands are not very pure and are frequently rather calcareous, but, as shown above, some of them are of considerable value.

The **Fullers' Earth** formation below the Great Oolite consists of grey clay or marl with beds of soft limestone, but contains no sand of commercial value.

The **Inferior Oolite,** consisting of sands with overlying limestones, extends from Burton Bradstock and Bridgeport to Yeovil, Bath, Dundry, and the Cotswold Hills. Several beds of sands occur in the north-west of Oxfordshire. These sands are usually ferruginous and, in some cases, contain a considerable proportion of calcareous matter as well as heavy minerals and fine mica.

The **Midford Sands,** which belong to this formation, consist of a mass of yellow quartzose sands with occasional bands of calcareous, concretionary sandstone, passing, in the Midland counties, into a dark-brown ferruginous and fossiliferous rock. They occur in Dorset between Bridgeport and Burton Bradstock, and extend from near Crewkerne by Ham Hill and Yeovil to Bruton and Doulting in Somersetshire. These sands cap the hills of the Glastonbury Tor and Brent Knoll. Their thickness varies considerably in different localities; it is nearly 200 ft. on the coast

at Bridport and 150 ft. in Somersetshire, but decreases to 20-30 ft. in Gloucestershire; farther north the Midford sands are seldom more than a few feet in thickness. Some of the Midford sands are exceptionally fine and might almost be termed " dusts."

CHALK OR CRETACEOUS SYSTEM

The Chalk or Cretaceous system comprises the Hastings sands, Wealden beds, Greensands, and various chalk deposits. The beds are divided into two groups according to their mode of origin, the Wealden beds and Hastings Sands (fluviatile) being formed in a delta, whilst the Chalk and Greensands formations as well as the Speeton clay are of marine origin. The Punfield beds, which are classified under the Wealden, are really of marine origin but have become mixed with chalk in the beds formed by fluviatile action. It is probable that the great Wealden river or delta was in process of formation at the same time as the marine fossils of the Lower Chalk were being deposited in other areas. As the sea advanced this delta was also submerged, so that whilst the fluviatile deposits must be older than the marine ones above them, the two kinds of deposits were to some extent contemporary. The Marine or Neocomian deposits extend down to the Jurassic rocks at Speeton in Yorkshire, but in the south of England only the upper division appears, and lies above the Wealden series, indicating the gradual submergence of the Wealden delta beneath the sea.

The **Wealden Beds** lie immediately above and may be said to form part of the upper portion of the Oolite formation, being separated usually from the Purbeck beds by the Hastings sands. They are characteristically fluviatile in origin, and probably formed the delta extending in an easterly and westerly direction for at least 200 miles and north and south for 100 miles, but the present visible area is far smaller than this owing to the superposition of later formations—chiefly chalk. The chief Wealden area commences north of Midhurst, and extends in a north-eastwards direction through Surrey, and eastwards through Kent to the borders of Romney Marsh and Hythe and south-eastwards through Sussex to Eastbourne. The beds also form a large vale below the Lower Greensand scarp of Leith Hill and Hindhead (Surrey), extending to the north, west, and south of Ashdown Forest.

Wealden beds, consisting of alternate clays and sands, also occur in the Vale of Wardour (Wilts.), and in Berkshire, Oxfordshire, Buckinghamshire, Bedfordshire, and Cambridge, but are of small commercial value.

In the Isle of Wight alternating layers of Wealden sands and clays occur on the southern portion of the island, and on the mainland they fringe the bay north of Swanage and round Lulworth.

The Wealden beds consist of—

(1) *Punfield beds*, containing a little chalk.

(2) *Weald Clay*, consisting of thick blue clays and brown shales, septaria of argillaceous ironstone, and beds of shelly limestone.

The **Hastings beds**, which occur immediately below and occupy the elevated ground in the Weald at Trowbridge, Tunbridge Wells, Crowborough, Ashdown, Mayfield, Heathfield, and Hastings, consist of—

(1) *Tunbridge Wells sands*, about 200 ft. thick, which occur in the neighbourhood of the town of that name and are used in the manufacture of tiles and facing bricks in conjunction with the local clay deposits. They are very similar in character to the Ashdown sand beds.

(2) *Wadhurst clay*, 150 ft. thick, which is used in the manufacture of common bricks.

(3) *Ashdown sands*, about 150 ft. thick, which consist of a soft buff or white sand and sandstone.

(4) *Fairlight clay* is about 360 ft. thick, and is similar to the Purbeck clays beneath.

The Lower Beds of the Wealden, including the Ashdown and Tunbridge sands, are often cemented by calcareous and ferruginous matter, so that they are not usually of great value. Some of the purer Ashdown sands near Hastings and Rotherfield, and the Tunbridge Wells sands at Tunbridge Wells, East Grinstead, Mayfield, and East Hoathby, have been used for glass manufacture. On the coast the Ashdown sands (associated with lignite) are exposed in the cliffs above the Fairlight clays and form a ridge extending 2-3 miles overlooking Hastings; parts are very pure and are suitable for glass manufacture. Similar deposits in the same formation occur at Bulverhyth, where the thin sands are covered by about 30 ft. of sands, silt, and clay, but crop out at the surface not far distant, where, however, they are less pure.

At Ashurstwood, near East Grinstead, the Tunbridge Wells sands forms a soft sandstone which is, in some places, somewhat ferruginous, but other portions are quite pure and are suitable for glass manufacture.

The **Greensand** formation is one of the most important sand-bearing deposits in the country and lies above the Wealden. It consists of two beds, named respectively Upper and Lower Greensand, separated by Gault clay. The sand beds occur as shown in Table VII.

Table VII.—Greensand Formation

Upper Greensand	Greenish-grey and brown sand and chert.
Gault	Stiff blue clay with septaria nodules.
Lower Greensand	Green and brown sands with pebbles, beds of gault, chert, and limestone (Kentish rag) divided into— Folkestone beds. Sandgate beds. Hythe beds. Atherfield clay.

The beds are typically of marine origin and were formed in shallow seas after the subsidence of the Weald. As submergence increased, the beds passed into a fine soft white limestone known as chalk. The Greensand formation takes its name from the green grains of the glauconite (iron silicate) which they contain. The name is, however, misleading, as the general colour of these sands is dark brown.

The **Upper Greensand Beds** are not so important as those occurring at the base of the formation, being less pure and more indurated. They extend over a considerable area in the Isle of Wight, Wiltshire, and Kent.

In Kent there is a thin outcrop of Upper Greensand fringing the northern boundary of the Lower Greensand, extending from Westerham to the coast. The beds consist of light-coloured quartzose sands and soft sandstones calcareous and glauconiferous in parts. In East Kent the Upper Greensand is only about 15 ft. thick; near Godstone and Merstham it is 25-30 ft. and forms a soft white sandstone. In the western parts of the Weald the beds are thicker but contain clay.

In the Isle of Wight the Upper Greensand attains a thickness of about 150 ft. At Didcot in Berkshire it is about 100 ft. thick and consists of an upper bed of light sand with a lower bed of dark green sand and a still lower one of hard sandstones with cherty beds.

Near Devizes it is 150 ft. or more thick, but far from pure.

Upper Greensand beds also occur at Penselwood and Chard in Somersetshire, and outcrop along the foot of the Chiltern Hills.

The Upper Greensand outcrops near Kingsclere, and appears also from Alton to Petersfield on the borders of Surrey.

The **Lower Greensand Beds** are of great importance and are largely employed, especially in the manufacture of glass, on account of their purity. They vary greatly in thickness, but the average is—

Folkestone beds	150 ft.
Sandgate beds	90 ,,
Hythe beds	200 ,,
Atherfield clay	40 ,,

In the Isle of Wight they are up to 800 ft. thick, but thin off to the west and north-west over older strata. In the south of England the Lower Greensand is chiefly found in Surrey and north-west and south-west Sussex.

The *Folkestone beds* consist of light-coloured quartzose sands often full of sponge spicules with seams of chert and beds of grit. In mid-Kent the chert beds are more pronounced. To the west the beds are more ferruginous and the thick sands contain irregular beds of compact iron-sandstone and ironstone-grit, as in the sand-hills around Haslemere and Petersfield.

The Folkestone beds near Godstone (Surrey) are rather irregular and ferruginous, and are subject to large variations in different parts

of the beds. Some portions are sufficiently pure to be employed for glass manufacture and for lining open-hearth furnaces, but the bulk is used as building sand and for agricultural and scouring purposes.

To the east of Godstone around Oxted and Limpsfield the Folkestone sands become rather coarse and ferruginous, and are suitable for commoner glass-ware and for open-hearth furnace linings. At Reigate (Surrey) they are purer than round Godstone and are more regular, though some calcareous material occurs in them. The beds in some places are 40 ft. thick, but are also covered by very thick beds of overburden which render them difficult of access. The sand is used for glass manufacture. Similar though less valuable deposits occur also at Westerham. In Sussex the beds extend from Midhurst to Petworth, Fittleworth, Pulborough, Storrington, Hassock's Gate, Ringmer, and north of Eastbourne.

In Kent the Lower Greensand extends from the south of Sevenoaks by Ashford to Hythe and Sandgate, the uppermost beds belonging to the Folkestone series. At Aylesford the Folkestone beds consist of pale grey or cream-coloured sands sloping in a northerly direction. They are contaminated, to some extent, by chalky matter, but the better qualities are used for glass of various kinds, and are suitable for lining open-hearth furnaces. At Hollingbourne and Berstead the same beds are also worked for glass sand for use in bottle manufacture.

The Kent beds are similar to those at Godstone and Reigate in Surrey, the sands occurring in caves as at the last-mentioned place. The lower beds consist of the Sandgate and Hythe beds, the latter containing soft layers of sand or "hassocks."

Several isolated areas occur in Oxfordshire, one at Cliddesden, one three miles south of Oxford, and another at Nuneham Park; the main mass extends in a thin strip from Shellingford to near Devizes. On Shotover Hill the beds overlie the Portland series, and near Oxford the sand beds are mixed with ochre and fullers' earth. At the base of the Greensand at Seend and Devizes (Wiltshire) is a bed of pisolitic iron ore 10-12 ft. thick, which is quite loose and friable and resembles a sand. The ore at the former place is used as a source of iron, whilst some of the sand is used as a moulding sand.

In Hampshire the Lower Greensand occurs at Petersfield and extends in a north-west direction along the London and South-Western Railway to Guildford and thence almost due east to Maidstone and *via* Ashford to Hythe. Another area extends southwards from Petersfield *via* Midhurst to near Eastbourne.

The southern half of the Isle of Wight is largely composed of Lower Greensand, which is in parts (particularly near Ventnor and Chale) overlain by Upper Greensand and Gault.

The Isle of Purbeck contains isolated deposits of Lower Greensand.

The Lower Greensand occurs in the north of the Chalk area in Berkshire and Cambridgeshire. The Faringdon beds are probably on the same horizon as the Folkestone beds, but occur only round Faringdon (Berks.). They consist of thick, pebbly, ferruginous sands partially consolidated and full of sponges, polyzoa, echinoderms, mollusca and foraminiferae. The pebbles are composed chiefly of white quartz, but also include quartzite, veinstone, jasper, slate, etc., from palaeozoic rocks.

The Lower Greensand in Norfolk is very different to that in South England. At Heacham and Castle Rising the middle portion, used for brickmaking, consists of clay with loamy layers and ferruginous nodules, but the Carstone above it is a good building stone.

To the south of Leighton Buzzard the Lower Greensand crops out beneath the Gault clay and extends north towards Woburn and to the north-east towards Ampthill and Biggleswade. The hills of Woburn, Apsley Guise, and Ampthill in Bedfordshire consist largely of sand belonging to this formation, together with beds of fullers' earth and some boulder clay. The sands of this formation largely consist of coarse material, which in places gives way to finer beds of cherty gravels and is associated with peaty material. They are suitable for a variety of purposes, particularly for filters, concrete making, grinding, etc. The more ferruginous parts of the beds are used for building, whilst some parts are used in foundries and steelworks. Some of the better qualities of sand are used in glass manufacture, and the cherty material is employed in grinding plate-glass. At Flitwick the sands are less pure than in the immediate neighbourhood of Leighton Buzzard, and can only be employed where their purity is not of first importance.

The Lower Greensand beds also occur at Hunstanton, Sandringham, Downham Market, and in the neighbourhood of Kings Lynn at Middleton and Gayton, the formation occupying a thin strip of country on the eastern side of the Wash and comprising the *Sandringham sands*. The outcrop appears above sea level at Heacham in the north and extends southwards, becoming broader and attaining its greatest breadth between Sandringham and the Nar valley. The sand beds are for the most part thick and moderately consistent, but rather ferruginous. They consist chiefly of fine-grained, sharp siliceous sand of colour varying from pure white to buff or yellow, due to the presence of iron compounds and to the decomposition of pyritic nodules. Grey or greenish loamy bands occur in various parts of the beds and sometimes make the working difficult. The upper part of the beds, of a thickness varying from 30 to 50 ft., is the most valuable and comprises the "white sands" of this series. The lower part of the beds consists chiefly of green or ferruginous loamy sands containing phosphatic nodules and resting on the Kimmeridge clay.

The Lynn sands are used chiefly for glass-making, but some is also used for open-hearth furnaces and other refractory purposes,

for moulding sand, and for building. A small amount is also used for abrasive purposes. The red sands of the Lynn beds are used for making dark-coloured bottles.

Near Gayton the beds become less pure and more felspathic, a are used for inferior glass and also for furnace-hearths. Simil beds occur to the north-east of Gayton, and vary from 30 to 40 ft in thickness; they are covered by Glacial Drift, and are used fo bottle glass.

The best portions of the Lynn sand are approximately equivalent to the Dutch and Belgian glass-sands imported into this country.

At Hartwell, near Aylesbury, Buckinghamshire, the Lower Greensand beds are worked for glass-making. To the west of Aylesbury, at Stone, the sand is very pure and white, and occurs in a bed about 18 ft. in thickness, the sand being broken by interstratified seams of peaty and ferruginous material which make working somewhat difficult. This sand is largely used in the manufacture of flint glass. The best qualities of sand from Aylesbury in Buckinghamshire are equal to, though of less extent than, the Fontainebleau sand, and are among the best glass-sands in the country. In some places in Buckinghamshire these beds have lost their sandy nature and have been cemented into a hard rock.

To the north the Greensand occupies a long straggling area from Grassby and Caister to Spilsby and Alford in Lincolnshire.

In Ireland the Hibernian Greensand corresponds to the Lower and Middle Chalk beds of England, and consists of green and yellow glauconitic sands with beds of grey marl and chert, the sands in some places weathering to a red colour These beds vary in thickness from 10 ft. near Larne to 80 ft. near Belfast.

The **Gault** which separates the Upper and Lower Greensands is of no importance as a source of sand, as it consists, for the most part, of a stiff black or dark blue clay of marine origin. It is occasionally sandy and calcareous, and usually contains nodules of pyrites, marcasite, and phosphate of lime; layers of greensand and septaria also occur.

The **Chalk** formation occupies a large area, particularly in the south of England, but it is unimportant as a source of sand, no noteworthy amount of commercial sand being obtained from it.

TERTIARY SYSTEM

The Tertiary System includes all the materials deposited after the Chalk and before the Glacial Drift. These deposits are usually well defined, some being of marine and others of fresh-water origin, and of somewhat loose texture. They consist chiefly of clays and sands, with sandstones, grits, and marls as accessories. They may be arranged as shown in Table VIII.

TABLE VIII.—TERTIARY SYSTEM

PLIOCENE . .	Mammaliferous Crag of Norfolk and Suffolk. Red Crag of Norfolk and Suffolk. Coralline Crag.
MIOCENE . .	Supposed, on palæontological grounds, not to be represented by any of our British strata unless the leaf beds of Mull, the lignites of Antrim, and the lignites of Bovey Tracey in Devonshire belong to this period. This is extremely doubtful.
OLIGOCENE .	Hamstead Beds, Bembridge Beds, Osborne Beds, Headon Beds.
EOCENE . .	Barton Beds, Bracklesham Beds, Bagshot Beds, London Clay Beds, Oldhaven and Blackheath Beds, Woolwich and Reading Beds, Bognor Beds, Thanet Beds.

In England the Tertiary rocks have suffered no internal change from igneous action, though they have been much displaced since their formation ; they now chiefly occupy the basins of London and Hampshire, and are represented by the steeply inclined strata of the Isle of Wight.

The **Eocene** strata are very important as a source of sands, many of the beds yielding valuable deposits. They may be divided into two sections, the Upper and Lower Eocene formations, the former containing the Bagshot, Bracklesham, and Barton Beds, and the latter the Thanet, Bognor, Woolwich and Reading, Oldhaven and Blackheath Beds, and the London Clay. These beds are included in the London and Hampshire basins, which commence on one side on the northern coast of Suffolk and pursue an irregular course in a south-westerly direction through Hertford (St. Albans), Essex, Kent, Surrey, and South Middlesex, Buckinghamshire to Berkshire (Windsor and Reading), and Hampshire. The beds also extend south-east from Charminster (Dorset) and north-east along the edge of the Upper Eocene, which lies over them, through Cranbourne, Downton (with an outlier at Salisbury) to Tycherley, then south-east through Bishops Waltham, Bursledon, Fareham, Porchester, Portsea, Havant, Chichester, Arundel, and Worthing to St. Lancing. Several outliers occur at Seaford. A narrow strip ($\frac{1}{2}$ mile wide) lies across the Isle of Wight from the Needles to Culver Cliffs. Commencing with several outliers at Great Bedwin, the beds also extend south of Hungerford, eastwards through South Berkshire and North Hampshire (with large outliers at Great Fawley, Winterbourne, Chieveley, Bradfield, Reading, Mapledurham, Shiplake, and Wargrave) to Windsor, Beaconsfield, with outliers at Turville, Taplow, Rickmansworth, Chesham, Abbots Langley, St. Albans, Uxbridge, through the greater part of Middlesex to Hertford. There are further outliers at Digswell, Dutchworth, and Sacombe.

Almost the whole of Essex, except the coast and the chief river valleys, is of this formation, as is also North Kent. In the last-named county, however, the main mass ends at Dartford, and the remainder consists of a series of irregular areas, all of

which are to the north of the railway line from London to Canterbury.

To the north of Essex the formation continues into Suffolk through Sudbury, Hadleigh, and Ipswich. South and east of Ipswich the formation becomes straggling and much overlain with Pliocene deposits, until it ends at Woodbridge and Orford.

The **Thanet Beds** consist chiefly of fine sands and clayey sands of marine origin, together with lignite, pebbles, coloured clays, shingle, and loam, with beds of rolled flint and marine shells. They nowhere exceed 60-80 ft. in thickness, and decrease westwards. As their name implies, they are well developed in the Isle of Thanet and in the northern part of Kent. In east Kent they pass downwards into thin beds of loamy clay, and in some parts to a sandy marl.

At *Charlton* (Kent) the upper parts of the Thanet beds are used for bottle glass, whilst the lower part, which rests on the Chalk formation, is worked for the famous "Blackfoot" moulding sand ("Erith sand"). A similar bed is worked in the vicinity of Rochester for use in bottle glass.

Between Erith and Crayford the beds are rather thin, but they become thicker again at St. Mary Cray, where they are heavily covered by Woolwich beds.

In Essex the Thanet beds only occur in the extreme south, and in a thin irregular line from Ware to Ipswich.

Towards the south and west of the London basin the Thanet sands become of small importance, the only valuable outliers occurring in Surrey, from the south of Croydon to Beddington (where the sand, which is covered with gravel, is used for making sand-lime bricks), and to the south-west of Banstead, at Walton-on-Hill, Warren Farm, and on Mickleham Downs. In Berkshire their place is taken by a loamy deposit, known geologically as the "basement bed" of the Reading series.

The **Bognor Beds**, which occur between the Thanet beds and the Woolwich and Reading series, consist chiefly of marine loams, and are not of importance as sources of sand, though the sand in them is valuable as a constituent of the material used for brick-making.

The **Woolwich and Reading Beds** comprise a series of coloured sands, pebbles, and mottled clays of very irregular character. At Reading and in the Hampshire basin they are mainly of fresh-water origin, but east of London they also contain estuaro-marine remains. They appear to have been deposited by a great river discharging into the Eocene sea near Woolwich, the estuary being occupied alternately by fresh and salt water. As the beds are traced westward they show increasing evidence of fresh-water origin, whilst eastward they become of an increasingly marine nature. These beds are most noticeable in the neighbourhood of the towns whose name they bear. The sands and loams of this formation are valued as additions to the fat clays from the same

beds which are used for the production of high-class tiles and terra-cotta.

The Woolwich and Reading beds consist of:

(1) Alternating layers of sand and grey clay rich in fossil remains.
(2) False-bedded sands rich in marine fossils.
(3) Reddish mottled plastic clays devoid of fossils.

The Woolwich beds are far less extensive than the Reading beds, and whilst well developed at Charlton, near Chislehurst, and Upnor, near Rochester, they are not found farther west than Croydon. Eastwards they develop into the Oldhaven-Blackheath series, and are thickly covered with buff and white sands.

Over the whole of Middlesex, Reading beds occur beneath the London clay.

In Suffolk the Reading beds consisting of fine sands and loams are valued in brick-making, being mixed with the highly plastic London clay, and in some cases used alone. The buff Reading sands of Norfolk and Suffolk and Essex have been suggested for glass-making, but have not as yet been used for this purpose to any great extent.

Between North Mimms and Hatfield Park the Reading beds are about 23 ft. thick, and are covered by 7 ft. of loam, 20 ft. of London clay, and several feet of gravel. Between Aldenham and Radlett the beds are sandy and laminated. Near Rickmansworth, Watford, Hatfield, and Hertford the Reading beds overlie the Chalk. In some places the sand and pebble beds are cemented into a hard rock. Between Rickmansworth and Harefield the Reading beds lie on the higher ground, though with a straggling outcrop, and run northwards on the hill-sides. Near Perry's and Moor Park there is a large patch of Reading beds (about two and a half miles long) which (unlike most of the formation of the district) is entirely free from a capping of London clay.

A little farther south, at Harefield, the Reading beds consist of 8 ft. of grey loam and 15 ft. of mottled grey and red clay, with alternate layers of sand and clay beneath, but the layers vary considerably in thickness.

Somewhat farther west, and immediately south of Amersham, two outliers of Reading beds occur. To the east of Chalfont St. Giles several other outliers of Reading beds again crop out. The Reading series is remarkably well developed around Beaconsfield, though much covered with gravel in places, except in the south, as at Hedsor, Brook End, and near Poyle, and intermediately at Hickenham.

Still farther south—between Mumford and Edgerley Hill, and expanding to both east and west—the Reading beds are extensively exposed, and, near Hedgerley, are about 30 ft. thick.

Reading beds occur to the south-east of Salisbury, round Clarendon Hill and Downton and near Great Bedwin, whilst near

the New Forest they are overlain by Bagshot beds. Reading beds occur in the north of Hampshire, extending from Farnborough to Silchester and westwards to Kingsclere. They also occur to the south of Winchester. In the Hampshire basin the sands are practically absent, only the clays being present.

In Sussex the Reading beds which occur at Newhaven and to the west of Brighton are concealed by the Coombe rock.

South of London the Reading beds are covered; they were formerly accessible on the north and west of Croydon, but building operations have stopped their use near this town. From a line joining Hog's Back, Merrow Downs, Great and Little Bookham, Ashtead, Epsom, and Ewell, the beds run in a southerly direction. Near Leatherhead, Ashtead, and Epsom the beds consist chiefly of a kind of sandy loam, which is used for gasworks refractory materials. There is a large outlier at Knowle Hill and to the south-west of Banstead at Walton-on-the-Hill, Warren Farm, and on Mickleham Downs the beds overlie the Thanet sands. The Woolwich and Reading beds run almost due north and south at Epsom, and swell out to a thickness of many feet in one locality, yet decrease rapidly in another. At Ewell there is about 20 ft. of clay and 10 ft. of sand, but, as already noted, the beds may vary considerably in thickness in other parts of the same district.

In the district round Aldershot the Reading beds crop out in a narrow band, running east and west about a mile from Weyburn and Tongham.

In Berkshire the Reading beds usually lie too far below the London clay to be available, except for an inlier near Mount Scipput to the south of Maidenhead, which brings them to the surface, where they consist of light and buff-coloured sands showing oblique lamination, with irregular beds and lenticular masses of mottled clays.

The greatest developments of the Reading beds are in the immediate neighbourhood of Reading, though their extension farther west to Hungerford and Marlborough is important. The sands are valuable, and are largely used, together with the clays found in the same district, for bricks, tiles, finials, and moulded terra-cotta works, etc., the combination forming one of the best red-burning materials in the country. The main mass lies to the east, west, and south-west of the town, but large outliers occur on the chalk downs to the north at Caversham Park, Chause Heath, Rotherfield, Peppard, and between Whitchurch and Woodcote. Farther to the east of the town of Reading the beds are thicker, but of little value. The beds usually have a superficial covering of gravel.

Although the general characters of the different beds are tolerably constant, they vary continually within small limits. Owing to this great variety each stratum must be kept distinct when working these deposits.

Around Marlborough the Reading beds lie in patches on the

highest ridges on the chalk downs, and form the remnants of the main Reading beds which once covered the Chalk. In Marlborough Forest the beds are too thin and too disturbed to be valuable.

The **Oldhaven and Blackheath Beds** form bands of sands and pebbles. They occur near Blackheath, Bromley, and near Oldhaven Gap east of Herne Bay, but are of small commercial value.

The **London Clay** contains no commercially useful beds of sand, but that which is mixed or stratified with it is of considerable value in brick-making, the clay alone being much too plastic to make satisfactory bricks. In some small areas, as at Watford Heath, the London clay overlies 16 ft. of clean sand, and at Harrow it is capped by Bagshot sands.

The **Upper Eocene Beds**, consisting of the Barton, Bracklesham, and Bagshot beds, lie above the London clay, and occupy an area from Chertsey and Weybridge west towards Woking, Aldershot, Chobham, Bagshot, Ascot, and Sandhurst, and again between Reading, Newbury, and Kingsclere. In the Hampshire basin these beds occur over much of the New Forest and west to Wareham, and extend in a narrow strip right across the Isle of Wight. These beds are chiefly comprised in two large areas: (*a*) the London basin, which is enclosed in a triangle, two of whose sides are formed by two lines drawn from a point twenty miles west of Reading, one passing through Norwich and the other through Canterbury; (*b*) the Hampshire basin, which comprises the Isle of Wight and a triangular area extending on the north to Salisbury, on the west to Dorchester, and east to Newhaven. Unfortunately, the sands in this large area are of small commercial value, as the beds are small and the sands very impure.

The **Bagshot Beds** form the lowest strata of the Upper Eocene formation and lie normally above the London clay, but are less widely distributed. The main mass of this formation occupies a large area bounded by Aldershot, Winchfield, Eversley, Wokingham, Ascot, Chertsey, Weybridge, Woking, and Ash, whilst smaller patches occur between Reading, Newbury, and Kingsclere. In the Hampshire area the Bagshot sands extend over the New Forest and westwards to Wareham, and across to the east of the Isle of Wight. The Bagshot beds also occur in the New Forest round Bournemouth. Though known as sands, they are rich in clays of a loamy character, and the more sandy portions are excellent for mixing with the tougher London clay, but have little direct commercial value.

In Essex the Bagshot series are limited to outliers near Brentwood, Rayleigh, east of Epping, Highbeech, Laingdon Hill, and a few smaller patches. The outlier extending from north of Rayleigh to just south of Hadleigh and south-west to Benfleet is of a very irregular shape. Around Hadleigh it is covered with pebbly gravel, but the remainder is practically free.

Bagshot sands form caps to the hills of Harrow, Hamstead, and

Highgate. At Finchley and Hendon cappings of boulder clay, sand, and gravel occur.

In Surrey, to the south of Esher, the Bagshot sands crop out on the higher ground, and are valuable deposits, though used only to a limited extent. In this district the area they cover is a rough triangle, with its apices at Esher, Ockshot Street, and Cobham. The Lower Bagshot beds consist chiefly of fine yellow clayey sands, with irregular beds of multicoloured clay especially abundant near Woking, Horsley, and Egham. They are also well developed to the east and south of Weybridge, but are much covered with gravel. At St. George's Hill and Weybridge the Bagshot beds are very pale and comparatively pure. It is possible that they might be used for glass-making and for the hearths of open-hearth furnaces.

There is a small outlier of Bagshot sand at Wimbledon.

The Middle Bagshot beds in this district are less argillaceous, the clays being very sandy, and towards Winchfield they gradually thin off. They are covered by thick beds of Greensand. The Middle Bagshot beds are also prominent on the high ground forming St. George's Hill and Red Hill.

The Bagshot beds are most conspicuous in the district from which they derive their name, lying between Ascot and Woking and extending north-westwards beyond Bracknell. Here the lower beds consist chiefly of a sandy loam which is largely used in brick-making.

Around Aldershot the Lower Bagshot beds run in a north-easterly direction and westward to the Horne and Ewshott. To the west of Aldershot the Upper Bagshot beds consist largely of sand; the Middle Bagshot beds are well developed to the north-east and north-west of Aldershot, beyond an outlier of Upper Bagshot sand. The beds consist of alternating layers of thin clay and good sand, and extend westwards towards Crookham. At Fordingbridge, in West Hampshire, the Bagshot sands are white, grey, or coloured, and are associated with peat. White Bagshot sands are also worked in the neighbourhood of Lymington and Brockenhurst in Hampshire. Near Marlborough, on the extreme end of the London basin, Bagshot sands cover the outcrop of Reading beds between Oare and Bucklebury. They are more fully developed to the south of the river, and consist largely of fusible clayey sands. Upper Bagshot beds capped by gravel occur from Easthampstead Plain southwards to the further end of Chobham Ridge and westwards to Edgeburrow Hill, with three permanent outliers—one at Duke's Hill and the others on Bagshot Heath. They contain very little clay except in a few portions where sandy "rubber bricks" are made.

South and west of Wokingham the Middle and Lower Bagshot beds are also extensive, and the town itself is built on an outlier of the latter. The Upper Bagshot beds are very scanty in this district. Eastwards towards Windsor the Bagshot beds pass gradually into the London clay, and are frequently capped with a

stony deposit. The Upper and Middle Bagshot beds are the most sandy,—the Lower beds containing more clay, including the famous Dorset ball clays, which are associated with beds of sand of varying thickness.

Kaolin-bearing sands containing a large amount of tourmaline occur, associated with ball clays and lignites, in the Bovey basin, Devonshire, where they are worked for refractory purposes. South of Torrington in North Devon, clayey sands which occur in association with peaty clay are also worked for refractory purposes.

The **Bracklesham Beds** occur on the east and west of the Isle of Wight, and consist chiefly of sands, marls, and loams, together with lignite beds. They contain no beds of sand of commercial importance. At the western end of the Bracklesham beds both they and the Lower Bagshot beds are very sandy, and there is little to distinguish the two.

The **Barton Beds** may belong either to the Eocene or Oligocene formation, as there is very little distinction in this country between the Eocene and Oligocene beds. They are similar to the Bracklesham beds of the Isle of Wight, and occur extensively as loams in Hampshire and north-western Surrey. They are well developed between Lymington and Christchurch, near Portsmouth and Gosport, round Southampton, and in the Bagshot district. Like the Bracklesham beds, they contain few beds of sand of commercial importance, but some portions are useful for building and foundry work, and at Longtown, near Southampton, the Barton beds (15 ft. thick) have been worked for glass sand for many years.

The **Oligocene** formation occurs in the north of the Isle of Wight and on the Hampshire coast. It consists of fresh-water and marine limestones, and clays which are grouped as the Headon, Osborne, Bembridge, and Hamstead beds. The *Bembridge beds* contain intervening layers of sand, but they are not of great importance. The *Osborne series* contains various beds of calcareous sands interstratified between shales and marls, but the formation is very irregular and of little value. The *Headon beds* consist of clays, marls, and sands, with occasional beds of limestone and seams of lignite.

In the Headon beds are some very useful sands, the most important being the Headon Hill sands which occur in Alum Bay, Isle of Wight, and to the south-west of Yarmouth, where they are associated with beds of lignite and contaminated by ferruginous matter. These sands have been used for glass-making in the past, though not at present. Similar deposits occur on the opposite side of the Isle of Wight in Whitecliff Bay, but they are neither so pure nor so useful.

On the Continent the Upper Oligocene formation near Paris yields the famous Fontainebleau sand, which occurs in association with lignites.

The **Miocene** formation is supposed to be absent from the British strata, but on the Continent this formation contains very valuable

deposits of sand associated with braunkohle. The famous Lippe sand, which is largely used for glass-making and for silica ware, belongs to this formation, and occurs at various places in Germany, including Dörentrup in Saxony. A similar deposit, known as the Hohenbocke sand, occurs at Hohenbocke in Prussia, and is also of Miocene age.

The **Pliocene** or **Crag Series** consists of shelly sands and gravels, with occasional beds of shallow marine clays interstratified between them. It is divided into three portions, as shown in Table IX.

TABLE IX.—PLIOCENE FORMATION

A. Mammaliferous Crag of Norfolk and Suffolk.
- (*a*) Forest Bed of Cromer.
- (*b*) Weybourne Crag.
- (*c*) Chillesford Crag.
- (*d*) Norwich Crag.

B. Red Crag of Norfolk and Suffolk.
C. Coralline Crag.

The *Coralline Crag* consists chiefly of shells and polyzoa in calcareous sand, or it may be compact, forming flaggy beds of limestone. In some places it passes into indurated beds of calcareous sandstone from which the shells have been for the most part dissolved away.

The *Red Crag* consists of a deep ferruginous shelly sand together with loam. It contains an abundance of marine shells; many of them have been rolled and comminuted. It occurs at Walton-on-the-Naze and over a great part of eastern Suffolk, from Felixstowe to Aldeburgh. The upper part of the Red Crag beyond Aldeburgh passes into a pale shelly sand and gravel, which, together with newer deposits of like character, are grouped as the Norwich Crag series or Mammaliferous Crag, which extends from Dunwich to Norwich and Weybourn.

Pliocene beds also occur in pipes in the Chalk at Lenham and other places in the North Downs, in Cromer Forest, and also on the coast of Norfolk and Suffolk, but are of no commercial value.

The Pliocene sands at St. Erth, Cornwall, provide the well-known Cornish Red and Cornish Yellow moulding sands, but the deposits are of very limited extent and will be worked out in all probability within a few years.

Similar beds, probably of Pliocene age, occur near St. Agnes Beacon, Cornwall, the best beds occurring below the red sand and "candle clays." They have been used as refractory materials, but the deposits are not of large extent and would soon become exhausted if worked commercially. Most of the Pliocene sands of this country are very ferruginous and of inferior quality. The Belgian sands imported for glass manufacture are chiefly of Pliocene age.

POST-PLIOCENE SYSTEM

The Post-Pliocene System consists of—

(*a*) Recent deposits.
(*b*) Glacial beds.

The **Glacial Beds** consist of boulder clay or glacial drift clay, sand, gravel, and boulders. They form a "blanket" over a large part of the country, particularly in Northern England, Scotland, and Ireland, and are a product of a period known as the Glacial or Great Ice Age, when the surface of the land was covered with a thick and heavy ice mantle, which in its seaward descent smoothed and grooved rocks over which it passed, forming the lower boulder clay, whilst masses laden with boulders and gravel from other regions were dropped on to the surface and carried by the glaciers which flowed over the land. When the glaciers melted they left in the form of a deposit the material known as Glacial drift or "boulder clay." This material varies enormously in composition, but is readily recognised by the peculiarly marked boulders and other stones found in it. Most of the materials removed are carried away at the sides and on the surface of the glacier, and when deposited form a long irregular ridge or *lateral moraine*; some material falls through the ice on to the bed, and, with other material occurring there, is termed a *moraine profonde*; the material deposited at the end of a glacier is called a *terminal moraine*. The drift left by the ice sheet usually has an undulating surface with mounds and depressions, the latter being the sites of earlier lakes or marshes. The mounds are composed chiefly of stones, gravel, and sand, with some clay.

Towards the close of the glacial epoch the deposition of the boulder clay ceased and its denudation began. On the low plateaux of the eastern counties it is often succeeded by coarse gravels, largely composed of flint more or less water-worn. These occasionally include small intercalations of boulder clay, and have evidently been derived from it, and indicate movement by fairly strong currents. Similar gravels are found overlying the boulder clay in other parts of England, sometimes at great heights above sea-level. Occasionally the two are intimately related. For instance, a pit on the broad, almost level top of Gogmagog Hills, about 200 ft. above sea-level and four miles south of Cambridge, shows a current-bedded sand and gravel, overlain by a boulder clay, obviously re-arranged; while other pits in the immediate neighbourhood expose varieties and mixtures of one or other material. But as true boulder clay occurs in the valley below, these gravels must have been deposited, and that by rather strong currents, on a hill-top, a thing which seems impossible under anything like existing conditions.

Glacial drift is found alike on upland and vale, especially in the Midlands; but farther south its progress appears to have been

barred to some extent by the Chiltern Hills, and more definitely by Edgehill and the Northern Cotswolds, though there is a large tract of boulder clay between Dunmow and Epping, with an apparent extension southwards to Hornchurch, where it lies below the Thames gravel. This drift covers the greater part of Lancashire and Yorkshire; it is well seen in cliffs at Blackpool, Filey, and Withernsea. The drift above the Lias rocks occupies the eastern part of Leicestershire. The drift of the Midlands consists of gravel beds and gritty loam. In Yorkshire, beds of sand and gravel separate the more clayey portions of the glacial drift. In the north of Lincolnshire glacial drift occurs plentifully, with much glacial sand.

Norfolk is largely covered by boulder clay, except in the west; and the same material is scattered irregularly over Suffolk. North-east Norfolk has many fertile loams, with lighter lands of sand, gravel, and marl. The drift also covers much of Warwickshire and most of East Shropshire, but it is absent in Oxfordshire, except on the north-eastern border where it joins Buckinghamshire.

In the Welsh valleys much gravel is mixed with the drift.

In Scotland the drift is very extensive in Aberdeenshire, particularly in the east, where it is frequently more than 100 ft. thick. It also occurs extensively in Banffshire, Bute, Caithness, Dumfriesshire, Midlothian, Fife, Inverness-shire, Perthshire, and, in short, all over Scotland.

Ireland formed the western boundary of the British glacial drift, but also appears to have been the centre of another ice-sheet radiating from Fermanagh. The east and central portions of Ireland are extensively covered by drift up to 100 ft. and more in thickness, which contains very little clay, being almost wholly composed of silt, sand, gravel, and stones. The Green Hills or "Eskers" in the central plain are entirely composed of sand and gravel.

There has been much denudation since the drift was first spread over the land, as valleys have been scooped through it, separating it into outlying masses.

The drift is often divided into two parts, the Upper and Lower. The lower drift consists largely of clay containing boulders, with little sand and gravel; whilst the upper beds contain very little clay and few boulders, but consist largely of gravel, sand, and silt. These upper beds are probably derived from a rearrangement of the lower ones.

Glacial drift does not pay to treat mechanically in order to separate the sand from the other materials. All that can be done is to confine the workings to the more sandy portions of the deposit. For this reason a large proportion of the drift is of no commercial value as a source of sand, but some of it is useful. Thus the glacial sands of Lancashire between St. Helens and Ormskirk, at Crank, Rookery, Rainford, Kings Moss, Skelmersdale, etc., are worked to a depth of about 4 ft. The sands are brownish in colour,

and contain much peaty matter; they are suitable for common bottle glass and for the production of scouring soap.

Fairly pure glacial sands also occur at Carstairs Kames, near Glasgow, Parrock Hall, north of Barrow-in-Furness, and at Harrington and Workington (Cumberland); they are worked for pig-bed sand. Glacial sands occur in Durham, forming with various loams a bed about 60 ft. thick, the top and bottom portions containing the best sand. Glacial sand and gravel forms a low ridge to the south of Beighton, near Sheffield, where it is worked as moulding sand. Similar beds also occur round Mansfield. Small deposits of commercially useful glacial sand also occur in various other localities, but are not of great importance. Glacial sands are worked at Bentham (Yorks.) for moulding sand, and also at Heck, near Selby, for concrete and building purposes.

The Bridlington sands occur at the base of the boulder clay at Bridlington, and consist of particles of argillaceous greensands somewhat shelly and rather thin. They have apparently been detached from an older bed. They have been used as building sand, but are not very suitable for this purpose. The glacial sands round Carmarthen are loamy and somewhat micaceous. In colour they are yellow, buff, or grey, and contain minerals similar to the Lower Pliocene sands of Cornwall. These sands are used for building purposes. Some of the glacial deposits of Shropshire are worked for moulding sand. Drift deposits of sand and gravels and boulder clay partially cover the Lias and New Red Sandstone of Warwickshire, the Chalk in Central Norfolk, and also to some extent in the west of the county. At Gorleston and other places shells are found in abundance in the sand. They also overlie the Crag Rocks at Kensingland and Pakefield, and to the north of Lowestoft in Suffolk. In Suffolk they also occur at Sudbury and Ipswich. At the latter place they are worked for steel-moulding sands, and have been suggested by Boswell as suitable for furnace hearths.

Sands occur in the drift deposits which cover a large part of Ireland, the sands frequently containing considerable quantities of marine shells. The "manure gravels" of Wexford belong to this class.

The **Recent or Post-Tertiary** deposits include all those which have been formed since the "drift," and include the products formed by the action of the weather on many of the older rocks. They cannot be classified according to their position, but are preferably arranged according to the chief agent concerned in their origin, as is done in Table X.

TABLE X.—RECENT DEPOSITS

(a) Accumulations of sand, gravel, and alluvial silt in river valleys. (See Alluvium, Chapter III.)

(b) Terraces of gravel, etc., in valleys, marking former water-levels. High-level and low-level gravels.

(c) Deposits of sand, silt, shell-beds, and vegetable drift in estuaries, forming deltas.
(d) Ancient deltaic deposits, forming alluvial plains, carses, etc., partly of fresh-water and partly of marine origin.
(e) Lacustrine accumulations now in progress.
(f) Lacustrine or lake silts filling up ancient lakes.
(g) Shell and clay marl formed in ancient lake basins.
(h) Littoral silts, sand-drift, shingle beaches, etc.; raised or ancient beaches; submerged forests.
(i) Pelagic or deep-sea deposits and accumulations, as foraminiferal ooze, red-clay, burden of icebergs, etc.
(j) Calcareous deposits, as calc-tuff, travertin, etc.
(k) Siliceous deposits, as siliceous sinter, etc.
(l) Saline and sulphurous deposits from hot springs, volcanoes, etc.
(m) Bituminous exudations, as pitch-lakes and the like.
(n) Vegetable matter, peat-mosses, jungle growth, vegetable drift.
(o) Animal matter, shell-beds, coral-reefs, osseous breccia, etc.
(p) Soils—admixtures of vegetable and animal matters.
(q) Elevations and depressions caused by earthquakes.
(r) Displacements produced by volcanic eruption.
(s) Discharges of lava, scoriae, dust, and other matters.
(t) Aerial or wind-blown deposits, as the sand-dunes of the Lancashire and other coasts, and the material deposited under desert conditions.

The most important sands in these superficial deposits are the dune and shore sands. The **shore sands** of Britain are generally rather impure, and vary in colour from pale grey to dark brown. The purest are found on the Isle of Jura, which are produced by the disintegration of Dalradian quartzites. There are also a number of fairly pure shore and dune sands in Ireland, the principal ones being at Ardara (Co. Donegal), Ballycastle (Co. Antrim), Coalisland (Lough Neagh), the shores of the river Foyle, Millisle (Co. Down), Portrush (Co. Antrim), Rosslare (Co. Wicklow), Sandymount Strand (Dublin), Silver Strand (near Wicklow), and Sutton (near Dublin), whilst other fairly pure dune and shore sands have been reported at Montrose, Aberdeen, Culbin, Bamburgh, Hartlepool, Blyth, and Lowestoft. There are many other deposits, too numerous to name, of lesser purity which occur all round the coasts of Great Britain.

The dune and shore sands in this country are usually ferruginous except where they have been derived from the disintegration of some of the purer quartzites or sandstones. The purest dune and shore sands are used in some cases for glass-making. The Irish sands mentioned above have been used for this purpose, as also has the Jura sand. Only inferior qualities of glass, such as common bottle glass, can, however, be made from most shore sands, though the Jura sand may be suitable for better-class goods.

The shore sand at Swansea has been used for the hearths of copper-smelting furnaces.

The less pure sands are used for a variety of purposes, including building, concrete, etc.

Some of the shelly shore sands have been used for dressing land. Metalliferous shore sands occur in many parts of the world,

and are valuable for the minerals they contain. Further information on shore and blown sands will be found under their respective headings in the next chapter.

Many **river sands** of recent age are dredged for various purposes. The Thames sand is used for concrete-making, brick-making, and as a moulding sand for casting iron. The sands of many other rivers are also used for similar purposes.

CHAPTER III

THE CHIEF CHARACTERISTICS OF VARIOUS SANDS

In this chapter the sands, and rocks from which sands are derived, are arranged alphabetically, the characteristics of each material being briefly indicated. This arrangement is more convenient than any other with regard to many of these materials.

Abrasive Sands are used for grinding and polishing various materials. At one time only natural sands were used as abrasives, but they have been largely replaced by artificial sands, produced by crushing emery, or the various artificial abrasives such as carborundum, corundum, etc. Many of these artificial sands are known by trade names. (See also *Carborundum*, p. 86, and *Corundum*, p. 93.)

Abyssal Sands are extensive masses of fine detrital material produced originally at great depths in the sea, by one or all of the following processes:

(*a*) Transport of material from the land to the sea and deposition in the latter.

(*b*) Deposition of calcareous, siliceous, and other materials (including the dead casts of shellfish, organisms) from sea-water.

(*c*) Deposition of material produced by subterranean volcanic eruptions, etc., and thrown into the sea.

The abyssal deposits usually consist of very minute particles. Their composition is extremely variable, though often very constant over relatively large areas. Deposits which are at present covered by a sufficient depth of water to be correctly termed "abyssal" are of no commercial value, as they are almost inaccessible.

Adobe is a term used for a sandy material, sometimes containing a considerable proportion of clay, which occurs in the plains and basins of the Western States of North America and in some of the arid parts of South America, and is very similar to the "loess" of Europe and Asia. It is probably of fluviatile origin, though possibly partly due to aeolian action. It is not found to any great extent in this country. This "adobe" should not be confused with the *adobe* used in the counties of Devonshire and Cornwall and some parts of Somersetshire for building; the latter consists of a mixture of clay or earth, stones, straw, and hair.

Aeolian Sands, see *Blown Sands* (p. 82).

Alluvium is a general term used to denote any material derived from pre-existing rocks which has been carried by water from its place of origin to an estuary or other situation where the reduction of the speed of the water permits deposition. Alluvium occurs in deltas, mud-flats, and similar deposits, and the particles may be of any size from the finest mud to pebbles ; usually, however, it consists of a mixture of silt and sand.

Alluvial deposits occur very extensively in the east of England, in Yorkshire, Lincolnshire, Cambridgeshire, and Nottinghamshire ; also around the Wash and on the coasts of Suffolk, Essex, Kent, and Sussex. To the west they are found in Somersetshire and Lancashire, but seldom in Wales, except for a small patch to the south of the mouth of the Dovey at Llanefelyn and on the northern coast of the Bristol Channel between Portskewet and Cardiff.

Alluvial deposits are sometimes of considerable depth, those in the Thames Valley at Tilbury Docks being nearly 60 ft. deep.

Alluvium frequently contains calcareous matter, the proportion varying in different districts, according to the conditions under which the deposit was formed. Many alluvial deposits contain metalliferous sands. (See *Placers*, p. 133, and *Gem-sands and Gravels*, p. 112.)

The material found in vales filled with glacial drift or boulder clay is sometimes termed alluvium, though a closer examination will show that it is of glacial origin. Hence the term " alluvium " when used by some writers must be understood as referring to superficial deposits as distinct from solid beds, rather than to those of definitely alluvial origin.

Arênes are sands produced by the decay of various igneous rocks, especially basic rocks such as trap-rock, basalt, etc. They are slightly hydraulic, and are similar, though far inferior, to pozzuolana (p. 136) and trass (p. 165). Table XI. shows the composition of some French arênes.

TABLE XI.—CHEMICAL COMPOSITION OF ARÊNES

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Na_2O.	K_2O.
St. Astier (Vicat) .	38·54	20·0	12·0	8·0	nd.	nd.	nd.
St. Servan (Vicat) .	42·1	23·65	22·47	trace	..	1·28	
Chateaulin (Vicat) .	60·3	23·7	10·3	trace	2·5	3·2	

Argillaceous Sand, see *Clayey Sand* (p. 92).

Asphaltic Sands contain a varying proportion of asphalt or natural bitumen. They occur in various parts of the United States associated with the usual mineral impurities found in sands, chiefly felspar and mica. They contain usually up to about 20 per

cent of asphalt, though some contain up to 60 per cent. They occur also in Alberta, Canada, Mexico, Cuba, and Trinidad. In Europe they occur at Bastennes, France, and Bikar, Austria. In Africa deposits occur in southern Nigeria. They are used in the preparation of asphaltic pavements and other bituminous coverings.

Backing Sand is the sand which is used to form the greater part of the sand moulds used by foundrymen in casting metal. It is " faced " with a layer of *facing sand* so as to secure a smooth surface on the castings and to enable the details to be true to the desired shape.

Bagshot Sands are of marine origin, and occur in the upper part of the Eocene formation. Their occurrence has been described previously (p. 70). The sands vary in colour in different parts of the beds from white to grey or brown. They are seldom pure white, though the colour is not always a sign of the presence of an excessive proportion of iron compounds, as they frequently contain carbonaceous and peaty matter, which discolours them but is fairly readily removed by washing or burning.

The proportion of impurities present varies considerably. In some cases as much as 24 per cent may be present, but in other localities the purer beds are quite low in impurities. In the Bagshot sands at Fordingbridge in Hampshire, according to Boswell, the impurities only amount to about 1 per cent. The minerals present chiefly consist of felspar, ilmenite, leucoxene, kyanite, tourmaline, zircon, and rutile. A little flint is also present in some cases.

According to Dick,[1] the proportion of the various minerals present is approximately as follows :

Quartz	75	Zircon	0·5
Felspar	20	Rutile	0·2
Iron ores	2	Tourmaline . . .	0·1
Clay	1	Various	1·2

The proportion of iron present usually exceeds 2 per cent in the more impure beds, but is much smaller in the purer ones.

The texture of the sands varies considerably in different localities, and no general summary can be made. At Fordingbridge, according to Boswell, about 88 per cent of the grains are between 0·25 and 0·5 mm. diameter, whilst the total amount of true sand is about 99·5 per cent. At Longtown (Hants), however, 90-94 per cent of the grains are less than 0·25 mm. diameter, whilst the Lower Bagshot sands of the Isle of Wight contain about 76 per cent of grains between 0·1 and 0·25 mm. diameter, and only about 8 per cent over 0·25 mm.

The proportion of " clay " present varies considerably, the range being generally between nil and 5 per cent.

The Bagshot sands of Fordingbridge are being developed for

[1] *Nature*, xxxvi. p. 91.

the manufacture of glass, and those in the Isle of Wight have been used in the past for the same purpose, though they are not at present worked. Bagshot beds are also worked for other purposes, such as brick-making, building, etc.

Bann Clay is not a clay but a large deposit of diatomaceous earth occurring in association with peat in the Bann Valley, south of Lough Beg (Co. Antrim, Ireland). It is non-plastic, and is used in combination with a stiff clay to make bricks. Deposits of a similar nature to this occur at Glen Shira, in Argyllshire; also a little north of Loch Kinnord and in the Isle of Skye. They should be regarded as *sands* and not as clays.

Barton Sands occur in the Upper Bagshot beds of the Eocene formation in Hampshire and the north-western portion of Surrey. Their occurrence and distribution have been described on p. 72.

At Longdown, near Southampton, the beds include about 15 ft. of a very fine cream-coloured sand containing, according to Boswell, 95 per cent of silica and only about 0·1 per cent of iron oxide. On burning, the colour is changed to brownish. It consists chiefly of grains between 0·1 and 0·25 mm. diameter, and 1-3 per cent of "dust" is present, the total amount of true sand varying from 93 to 98 per cent. There is about 0·8 per cent of heavy detrital minerals present, including tourmaline, kyanite, ilmenite, magnetite, limonite, zircon, and rutile, with a smaller proportion of epidote and hornblende. Muscovite is very abundant. This material has long been used for glass-making.

Beach Sand, see *Shore Sand* (p. 157).

Bituminous Sands are those containing bituminous matter in sufficiently large amounts to render it an important constituent. *Asphalt sands*, *tar sands*, and *oil sands* belong to this class.

Black Sands are so called on account of their colour when freshly won. They may owe their colour to various causes, including, in some cases, an excessive amount of carbonaceous matter, though the colour is usually due to the presence of magnetic iron oxide (magnetite) or other minerals, such as ilmenite, cassiterite, manganese dioxide, etc. The principal black sands are found in the United States, Canada, New Zealand, Africa, Russia, and Siberia.

The so-called "black sands" of New Zealand are also rich in titanium minerals.

Black sands frequently contain valuable minerals such as gold, platinum, etc. The "black sand" of the Rand consists chiefly of iron sulphide, together with a paying quantity of gold, small quantities of iridium, osmiridium, and, in some cases, platinum and other metals of the same class.

Blown or **Aeolian Sands** are those produced by the action of the wind-borne particles on rocks, as described on p. 22. They are widely distributed, occurring chiefly in hot, arid regions and along the sea-coasts. In this country they occur in many places around the coast where there is an expanse of sea sand at low

tide ; the wind drifts the material inland, where it becomes l up into dunes, which sometimes rise to a height of 60-80 f. some places, as in Cornwall, much of the blown sand is made up of comminuted shells ; elsewhere it is mainly quartz sand.

The chemical composition of blown sands depends to a large extent on the original rocks from which they have been derived, and the extent to which they have been mixed with other materials during their transference from one locality to another. They may be derived from almost any rock, and consequently no rule as to their composition can be given. A blown sand derived from a quartzite or sandstone rock may consist almost wholly of quartz grains with very little admixed impurity; but one derived from a basic igneous rock may contain much mica and felspathic matter, whilst one consisting chiefly of comminuted shells will be largely composed of calcium carbonate. Generally, they contain little or no organic matter except where they have engulfed a fertile region and then receded, carrying some of the decomposed organic material along with the sand.

The colour of blown sands is very variable ; some are pure white, whilst others are of all colours, from that of cream to brown or even darker shades, according to the impurities present. Most blown sands are grey or pale brown.

The texture of blown sands is also variable on account of the mixing and re-mixing of the deposits and the frequent changes in the speed of the wind. The latter causes grains of varying sizes and specific gravities to be picked up and dropped again according to the different velocities at which the wind travels, with the result that the separation of the particles of various sizes is not very good unless the sand is subject to some prevailing wind.

According to Boswell, the most uniform blown sands in the country are those of Aberdeen, Montrose, Bamburgh, Hartlepool, and Blyth, which contain over 90 per cent of grains between 0·25 and 0·5 mm. diameter, together with 0·5–3·5 per cent between 0·1 and 0·25 mm. diameter. The proportion of the finest grains in these sands is seldom more than 2·5 per cent, except at Aberdeen, where the blown sand contains 3·5 per cent of grains less than 0·1 mm. diameter. The Aberdeen sand also has about 2 per cent of grains over 0·5 mm. diameter, and the Blyth sand has 1·3 per cent. The blown sands at Curracloe (Rosslare), Lowestoft, Ballycastle (Co. Antrim), Sutton, Culbin, and Coalisland (Lough Neagh) are not quite so uniform, the first four containing between 80 and 90 per cent of grains between 0·25 and 0·5 mm. diameter, and the last two containing between 70 and 80 per cent. The Sutton (Dublin), Lowestoft, Ballycastle, and Coalisland sands are rather coarse, containing respectively 15, 16, 19, and 27 per cent of grains over 0·5 mm. diameter. The Culbin sand contains 22 per cent of grains between 0·1 and 0·25 mm. diameter, whilst the Curracloe sand contains nearly 10 per cent.

Of the various impurities, the most important are calcium

carbonate and iron compounds, though these are not detrimental for many purposes.

The proportion of iron oxide in blown sands is generally fairly high, though some of these sands are much purer than others.

It is a noticeable fact that the heavy detrital impurities in blown sands consist of very much smaller grains than the quartz present. This is due to the fact that the wind-speed is only able to lift a much smaller grain of a "heavier" mineral, with the result that the heavy minerals are usually concentrated among the finest particles of sand. On the other hand, flaky minerals, such as mica, may be carried along in quite large pieces on account of the surface they offer to the wind, so that such minerals are often present in large grains or flakes.

Bole is a ferruginous, sandy material of a reddish-brown or yellowish colour, containing about 41-47 per cent of silica, 18-25 per cent of iron oxide. Its composition is very variable, as it is a decomposition product of basaltic rocks. It occurs in relatively small quantities in various parts of the country; that in the north-eastern part of Ireland occurs as partings in basaltic sheets, associated with lithomarge, bauxite, pisolitic iron-ore, and lignite. In Asia Minor a bole containing about 32 per cent of alumina is found, whilst in Saxony it is almost free from iron oxide, only a trace being present. Bole has been used as a red pigment (including that used for tattooing), and in medical work as an astringent.

Bort or **Boart** is a coarse dark-coloured sand, consisting of an impure variety of diamond which is imperfectly crystalline and only partially transparent. It often occurs in small masses, which are reduced to "sand" by crushing them in a steel mortar. Bort is chiefly used as an abrasive by lapidaries. (See also *Diamond*, p. 96.)

Bracklesham Sands occur in the Upper Bagshot formation (p. 72). They are of greater geological than commercial interest.

Breeze is an artificial sand, consisting of sifted ashes. It is largely used in the manufacture of London "stock" bricks, as it is non-plastic, and so renders the plastic clays more workable. It also aids in the firing of the bricks. (See Vol. II., Chapter I.)

Brick-moulding Sand is that used in the sand-moulding process of brick-making, and also for producing a good colour on the face of bricks, which would otherwise look unsightly. It is usually of a marine or estuarine origin, such as the Bagshot beds (p. 70). Further particulars regarding the use of this class of sand will be found in Vol. II., Chapter I.

Brown Sands usually owe their colour to the presence of iron oxide or to carbonaceous matter, such as lignite, or, less frequently, to manganese compounds. The brownish or blackish sandy crust on desert rocks called "vernis du désert" usually consists of oxides of manganese, left as a residue after the evaporation of the water in the rocks, containing salts of these substances in solution.

Building Sand includes sand used in the manufacture of mortar,

concrete, and other materials used in building construction, and should always be a highly quartzose sand with sharp angular grains, and free from loam or clay, which, if present, must be removed before the sand is fit for use. Building sand may be of fluviatile, marine, aeolian, or estuarine origin, but glacial deposits usually contain too much clayey material. Where the cost of preparation is not excessive, building sand may be produced by crushing sand-rocks. (See also Vol. II., Chapters II.-V.)

Bunter Sands occur at the base of the Triassic system, and consist of marine and desert deposits, much of the material showing evidence of carriage by wind. The occurrence and distribution of Bunter sands has already been described (p. 53).

The sand-bearing materials in this system consist chiefly of soft sandstones of various colours, often mottled, and associated with clays and dolomites. They have usually a reddish tinge on account of the amount of iron present, usually as a thin film of haematite over each particle of sand or other minerals present. In some places they have a slightly greenish tinge, which, according to Boswell, is due in all probability to the reduction of the iron from the ferric to the ferrous state by decomposing organic matter, or to the action of algae, bacteria, etc.

The proportion of iron oxide varies; it is sometimes as much as 6 per cent, though in some localities it is extremely low, and the sands, *e.g.* the Lower beds at Worksop, may then be sufficiently pure to be used for glass-making.

They contain usually over 75 per cent of silica—some, such as the Lancashire sands, having, according to Boswell, over 90 per cent. Up to 9 per cent of alumina may be present, but generally not much more than 6 per cent. The proportion of lime, magnesia, and soda present is usually fairly small (less than 1 per cent), but the Mansfield moulding sand and the Belfast sands are rich in magnesia and lime.

A characteristic of the Bunter sands is their high proportion of potash, due probably to the fact that, being formed under desert conditions, the felspar did not decompose as it would have done had it been in contact with water. Most of the beds contain more than 2 per cent and some more than 5 per cent of potash. This greatly reduces their refractoriness, so that they cannot be used for casting steel, though they are quite suitable for moulding non-ferrous metals. Detrital minerals are generally abundant, and are specially so in Lancashire and Ireland, mica being very plentiful.

Having been formed under desert conditions, Bunter sands usually consist of well-rounded grains which are characteristic of this mode of formation (Fig. 1). They vary in coarseness in different parts of the beds and in different localities. Very often coarse and fine sands occur in the same locality, as at Mansfield and Worksop. At Mansfield, according to Boswell, the sand varies, some containing over 80 per cent of grains more than 0·25 mm. diameter, other parts nearly 80 per cent less than 0·25 mm.

diameter, whilst at Worksop the pot sand contains over 90 per cent of grains larger than 0·25 mm. diameter and the finest beds contain over 90 per cent of grains less than 0·25 mm. diameter.

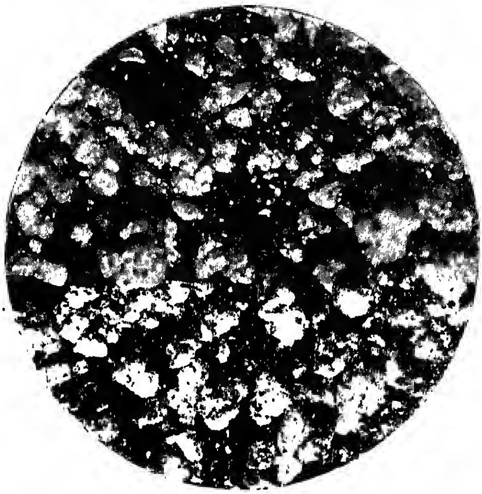

FIG. 1.—Mansfield Red Bunter sand. × 20.

The Belfast and Ormskirk sands are generally very fine throughout, the former having a fine silky texture, for which they are famous.

Calcareous Sands are usually of marine origin, and contain, in addition to their siliceous materials, chalk, limestone, gypsum, and other lime compounds in varying proportions. They are usually produced by the shells of dead marine animals becoming mingled with siliceous sands and ground into a very fine powder, so that in time the shells are scarcely recognisable, even under the microscope. Such sands are often of great value in agriculture. (See Vol. II., Chapter VIII.) For further information see *Shell sands* (p. 157).

Carbide Sands or **Fire-sands** are artificial sands composed of silicon carbides and carboxides, which are used as abrasives. *Carborundum*, *crystolon*, *carbosilite*, *carbofrax*, and *electrolon* are silicon carbides. *Silfrax*, *silit*, and some other compounds appear to be somewhat irregular mixtures of carbides and carboxides of silicon, together with some silicon nitride. *Siloxicon* and *fibrox* are carboxides of silicon, and correspond to some composition between Si_2C_2O and Si_7C_2O.

All these materials are produced in an electric furnace by the partial fusion of a mixture of silica and carbon in the absence of air. The furnace used (Fig. 2) is about 33 ft. long and 17 ft. wide and 10 ft. deep, the only permanent part of the structure being the long end walls and the floor. In each end is a large terminal, consisting of a number of carbon rods, the ends of which fit into copper plugs, which in turn are fastened into sockets in a copper plate bolted to the outside of the wall and connected to the leads. Between the terminal heads is a granular resistance core, about 3 in. diameter, made of pieces of coke about $\frac{3}{8}$ in. diameter. . The core is packed round loosely with a mixture of sand, coke, sawdust, and salt in proportions which depend on the nature of the product desired.

A typical charge consists of :

Coke	20 parts.
Sand	32 ,,
Sawdust	6 ,,
Salt	1 part.

The proportions of coke and sand used do not vary much, but the sawdust may vary from 7 to 11 per cent, and the salt from 1·5 to 4 per cent of the charge according to the products required. These mixtures provide a slight excess of carbon, to allow for loss. The function of the salt is to remove the iron and other impurities in the coke and sand by the formation of volatile chlorides, whilst the sawdust is added to make the mass porous, so that the carbon monoxide, when formed, may escape.

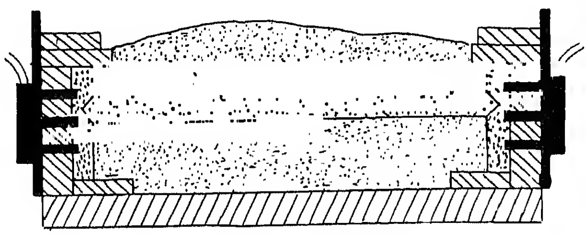

FIG. 2.—Carborundum furnace.

The reaction which takes place in the furnace is represented by the following equation :

$$SiO_2 + 3C = SiC + 2CO.$$

An electric current of about 230 volts and 6000 amperes is passed through the contents of the furnace, but after a time the current is increased and its voltage reduced until the heat is sufficient to vitrify the contents of the furnace and convert them into carbides, etc. The temperature and rate of heating must be skilfully controlled, as the nature of the products varies with the proportion of raw materials used and the conditions of heating and cooling. When the contents of the furnace are sufficiently cool, they are taken out carefully, each product being kept separate as far as possible. The products consist of some unaltered raw materials, together with silicon carbide and various by-products of the reactions, of which the more important are : (i.) the graphitic core surrounded by (ii.) a zone of crystalline carborundum, (iii.) a layer of carborundum powder, (iv.) a ring of siloxicon fire-sand with silicon monoxide, and finally (v.) a film of silica.

The various products are next passed through a mechanical crusher and digested with (1-2) sulphuric acid for three days at 100° C., after which they are washed and then further crushed and

screened, so as to separate into various grades, the finest portion being collected as *flour*.

Carborundum is a silicon carbide corresponding to the formula SiC; it is capable of formation in small quantities at a much lower temperature than that used in actual practice, but on the larger scale a very high temperature is essential. The material sold as "pure carborundum" contains about 65 per cent of silicon, 30 per cent of carbon, and 5 per cent of impurities. It is in the form of hexagonal crystals varying in colour from the palest yellow to grey or blue-black, the variations being due to impurities in the material and to the play of light on the surface of the crystals. The crystals are of intense hardness, with a specific gravity between 3·17 and 3·21, and a melting point of about 2500° C.[1] The refractoriness of carborundum is not known accurately, though the high temperature required for its manufacture shows that it can resist a very high temperature. It decomposes slowly at temperatures above 2200° C. without fusing; the silicon volatilises, and the graphite burns away. The rate of decomposition is often reduced by the formation of a siliceous glaze as one of the by-products, but this is not sufficiently protective to prevent its slow decomposition. In the presence of flue- or kiln-gases the decomposition is more rapid, carbon monoxide and silicon being formed. Carborundum has a high thermal conductivity, a low coefficient of expansion, and great strength and toughness.

It is used as a refractory material in the form of bricks, and as an abrasive in the form of "sand" or powder, which may be used direct or after being applied to paper or cloth, or it may be mixed with a suitable binding agent and made into blocks, wheels, and sharpening stones. Carborundum powder has been used to some extent in place of corundum for lapidaries' work, as it is harder. It has, however, the disadvantage of being more brittle and is soon reduced to flour. It is also used in place of emery, which is an impure form of corundum, as, although it is more costly, it does the work in one-third or one-quarter of the time taken by emery. It is used for glass-cutting and for polishing and grinding metals, etc., and instead of diamonds for drill-heads, for which purpose it is quite satisfactory if mounted in a suitable metallic or ceramic matrix. It is also used instead of ferro-silicon for steel-making and in the reduction of copper, nickel, and lead from their chlorides, the production of metallic silicides from their oxides, and the preparation of quaternary steels.

As a refractory material it is used for the manufacture of fire-bricks, zinc retorts, and refractory cements.

Carborundum powder is sometimes employed as a facing for sand moulds used for casting metal. When mixed with a suitable binder and applied to the mould, it gives the metal casting a hard surface, because some of the silicon from the carborundum enters into the metal and "case-hardens" it.

[1] Some samples show no signs of fusion at 2700° C.

Crystolon is the registered name for a variety of carborundum which is prepared at a temperature of 1820°-2250° C. A dark-coloured mass, known as amorphous silicon carbide or *fire-sand*, is formed at a temperature of 1600° C., and this is slowly converted at 1850° C. into crystalline crystolon; and as the temperature rises and approaches 2250° C., decomposition occurs, with the formation of other carbides and carboxides. Crystolon is not affected by acids, except hydrofluoric acid, but alkalies and carbonates decompose it when heated, and metallic oxides react with it at red heat. In an oxidising atmosphere, silicon carbide is decomposed, forming silica and carbon monoxide. The coefficient of expansion of crystolon is very low, being 0·0000045 c.g.s. units per degree C.

Silfrax is another form of carbide of silicon which is formed from the vapour of silicon acting on solid carbon. The pores in the latter soon become filled with silfrax, and the crystals so formed remain small and are tougher and stronger than carborundum crystals. Silfrax is formed at the same time as carborundum, though in a different manner, so that each must be separated from the other when either is required in a fairly pure state. Silfrax is used for the manufacture of refractory articles, chiefly pyrometer tubes and electrical fittings, in the same way as carborundum.

The *fire-sand* which is formed at a lower temperature is amorphous or crypto-crystalline, but it is equally as refractory as the crystalline material. It is, however, rather less stable than the crystals. It is attacked slowly at red heat by sodium carbonate, caustic soda, and sodium peroxide, and rapidly by red lead. It is not attacked by hydrofluoric acid to any appreciable extent. Fire-sand is used as a refractory material—chiefly in the metallurgical industries.

Silundum is a term introduced by F. Bolling, who, in 1900, found that when pieces of carbon, pressed or moulded to any desired shape, were heated in a mixture of silicon carbide and sand, the silicon reduced from the sand volatilised and combined with the carbon to form a compound the particles of which retained the shape of the sand. It is a silicon carbide with an excess of carbon, whereas silfrax and silit have an excess of silica. From a number of experiments made in 1914-1915, Tucker and Lowry concluded that the formation of silundum commences above 1300° C., the greenish slate-coloured variety being first formed, whilst above 1800° C. the steel-grey modification appears. Above 2200° C. the product is decomposed and graphitic carbon remains behind.

Tucker and Lowry conclude that the green variety is really a carboxide containing about 9 per cent of oxygen, but this decomposes to form the grey variety, which is a true carbide, devoid of oxygen and closely resembling carborundum. Both the green and the grey varieties of silundum are refractory; they are not attacked by oxygen, nitrogen, or hydrogen below 1100° C.,

nor by most fused salts; fused caustic alkalies and alkali carbonates convert the silicon into silicate; they are oxidised by peroxides and by lead oxides; acids, even hydrofluoric acid, are without action on pure silundum, but attack the impurities present in the commercial products. The density is about 3 and the hardness 9 on Mohs' scale. The most notable distinction between the two varieties of silundum and carborundum is their electrical resistance. The specific resistance of carborundum per centimetre cube at 25° C. is 50 ohms, whilst that of green silundum is only 0·2374 ohm. At higher temperatures all the carbides are fairly good conductors of electricity.

Siloxicon is a silicon carboxide produced in the same way as carborundum, but the conditions of manufacture are slightly altered. Siloxicon begins to form, according to Tucker, Gillet, and Saunders, at a temperature of about 1500° C. Its composition corresponds to Si_xC_xO, where $x = 1\text{-}7$ and averages about 2. It may be a solution of silica in silicon carbide, as hydrofluoric acid removes silica and silicon, but leaves any carborundum present unattacked. It is amorphous, usually has a greenish-grey sheen, and contains some free graphite and carborundum. It has a specific gravity of 2·52. It is highly refractory, a good electrical conductor, indifferent to most acids, but more easily oxidised at 1500° C. than carborundum, a superficial glaze being produced. When heated in a neutral or reducing atmosphere, it is unaffected until it reaches a temperature of about 1840° C., when it begins to decompose, forming carborundum, free silica, and carbon monoxide; at higher temperatures it dissociates, forming carborundum and free oxygen.

Fibrox (Eng. Pat. 16,299 of 1913) is a silicon oxycarbide prepared by heating a mixture of silicon and a catalytic agent such as fluor-spar. Carbon monoxide and dioxide enter the crucible by diffusion and slowly convert the silica into a fibrous mass, having a true specific gravity of 1·8–2·2. It is, however, extremely porous, 99 per cent of the volume being air, and its apparent specific gravity is only 0·0025–0·0030. It is used as a heat insulator.

All the foregoing carbides and carboxides are reduced to the form of "sand" before use. They are then sifted so as to grade the material into grains of various sizes, the sifted products being used in the form of powders or mixed with a suitable binding agent and moulded into blocks, etc.

For use as a refractory material the various silicon carbides need to be as devoid as possible of free carbon; this material, even when present in only small amounts, is a serious hindrance to that intimate contact between the bond and aggregate which is essential to the production of sound goods.

Carbonaceous Sands are those containing a considerable proportion of organic matter, which may be in the form of lignite or peaty matter. Many sands belonging to the Cretaceous and

Tertiary Systems are associated with lignite beds, whilst many glacial and most surface sands are associated with peaty or other organic matter. The presence of readily decomposable carbonaceous matter in association with sands is a considerable advantage in many cases, as the water percolating through these beds becomes charged with various soluble substances derived from the peat or other organic material, which reduce the iron compounds in the sand to the ferrous state and render them soluble. By this means the percentage of iron in the sand is gradually reduced. If the water is not able to escape, however, the ferrous compounds remain in the sand, and whilst in outward appearance it is pale in colour and apparently low in iron, its normal colour is restored by heating it to redness in a current of air, when the ferric compounds are once more produced and the sand becomes brown or reddish.

The sands between St. Helens and Ormskirk in Lancashire are associated with a considerable amount of peaty matter, by means of which the proportion of iron has been reduced to a very small percentage (p. 115).

Carbonado is a dark grey or black variety of diamond, which is sometimes indistinctly crystalline, granular, or cellular in structure. It is sometimes called " black diamond," and was first discovered in Bahia, Brazil, though it also occurs in Borneo. It has a specific gravity of about 3·01 and contains about 2 per cent of mineral matter, which is left as " ash " on calcining the material in a gentle current of air. Carbonado is harder than all other varieties of diamond. It is chiefly used for rock drills and also for the tools used for dressing millstones and emery wheels (see also *Diamond*, p. 96).

China Clay Sand is the technical term applied to the particles of quartz and undecomposed granite occurring with china clay and mica in the slurry washed out from the china-clay rock, or carclazite, found in Devon and Cornwall. The sides of the china-clay pits or *stopes* are subjected to the action of a stream of water which, in its descent, carries with it some of the clay, together with quartz, mica, and other rock particles. The resultant cream or slurry is collected in a settling pit, in which the coarse particles or " sand " settle to the bottom, whilst the other materials are carried off in suspension in the water for further treatment in a *launder*. Sometimes a number of sand-intercepting boxes are used to retain the sand. A launder consists of a square wooden pipe (about 9 in. square), the sides being perforated by a number of 4 in. holes about a foot apart, fitted with stoppers, called *buttons*, which are removed in succession as the sand settles out of suspension, and so allow the water and clay to flow away. Where no launder is used, and in some cases in conjunction with a launder, the slip is turned into a sand-pit, which consists usually of a rough rectangular trough 3-5 yards long and 2-3 yards wide, with stone walls 4-6 ft. high. A doorway is placed at the lower end of the pit over which the clay slip passes, whilst the heavy sand sinks to the bottom

and is collected. Usually, two or more sand-pits are used, so that when one is full of sand the slip is turned into another, whilst the first is emptied out by means of shovels, the sand being conveyed to the top of the pit in wagons. Any sand which is not intercepted by the sand-pits is collected (together with some mica) in the first drags; it is removed from them and put with the residues from the sand-pits in huge banks or " burrows."

" China-clay sand " consists largely of quartz, undecomposed felspar, with tourmaline and some mica. The size of the particles varies from very fine grains up to pieces 2 in. or so in diameter.

The waste from the china-clay rock may form anything up to four-fifths or even more of the material, but only part of the waste can be used. Table XII., due to Mr. J. M. Coon,[1] shows the proportion of " sand " in the china-clay rock from the St. Austell district:

TABLE XII.—COMPOSITION OF CHINA CLAY ROCK

	A.	B.	C.	D.	E.	F.
1. Coarse quartz	39·80	29·80	51·40	33·30	25·30	37·50
2. Medium quartz	17·22	14·20	15·80	11·26	33·40	16·60
3. Fine quartz, tourmaline, etc.	1·82	2·40	1·60	3·93	4·80	2·10
4. Very fine quartz, coarse mica, tourmaline, etc.	1·16	1·36	1·20	2·03	3·33	2·13
5. Fine mica, coarse clay, tourmaline, etc.	0·98	1·41	2·50	1·46	3·63	4·20
6. Very fine mica, medium clay, tourmaline	1·57	1·81	2·50	4·60	3·45	4·40
7. Marketable china clay	37·30	49·00	35·00	36·60	25·80	33·00

Mr. J. H. Collins[2] found two samples of china-clay rock to consist of:

Water	5·0	5·5
Coarse sand and mica over 30-mesh	67·5	71·5
Fine sand and mica under 30-mesh	2·0	2·5
Fine mica and some clay	3·5	3·0
Fine clay	22·0	17·5

He found that, on an average, 3-7 tons of sand were produced for each ton of commercial china clay, and, in addition, 2-5 cwts. of coarse mica and 1-3 cwts. of fine mica were also obtained.

China-clay waste or " sand " is used for various purposes, including building, rough-cast work, garden paths, refractory bricks, cement, and also for polishing guns.

Clayey Sand is sand containing an appreciable proportion of clay or argillaceous material which may or may not hinder its

[1] *Trans. Eng. Ceram. Soc.*, x., 1911, p. 82.
[2] The Hensbarrow Granite District, Truro, 1878.

use. Such sands should only be employed where the presenc of clay will not be deleterious; they are useless for building though often quite satisfactory in brick-making and other clay-working processes. (See *Building Sand*, p. 84.) Clayey sands are excellent as "opening substances," and sometimes have an advantage over pure quartz. In some cases, as at Windsor, Ewell, Epsom, and in Wales, they are used for making firebricks. (See Vol. II., Chapter VII.) They are of wide distribution and occur in many parts of this country, and are often known as *loams*, though this term is more generally applied to sandy clays rather than to clayey sands.

Clayey sands may sometimes be used as a source of clean sand provided they are first washed very thoroughly (Chapter IX.) in order to remove all the clay, but the cost of this treatment is usually prohibitive.

Cobalt Sands, or cobaltiferous wad (see *Wad*, p. 167), are one source of the metal cobalt. One important variety of these sands, termed *asbolite*, is found in New Caledonia and near Port Macquarie in New South Wales.

Colluvial Sands, see *Diluvial Sands* (p. 100).

Copper Sand, found in Chili, consists of grains of metallic copper mixed with quartz.

Coral Sands consist largely of fragments of coral rock which have been broken from the main mass and reduced to powder by the action of waves, etc., and deposited near the shore. They contain varying proportions of mineral matter—chiefly of a volcanic nature. Coral sands, found further out to sea, pass gradually into fine calcareous muds of the same nature as coral sands, but are much finer in texture and are generally deposited at greater depths than the corresponding sands. As coral rocks are largely composed of calcium carbonate, the coral sands have a similar composition. They are of geological rather than commercial interest (see p. 35).

Corundum, sometimes called adamantine spar, is a source of abrasive sand. It is found in several varieties, from the coloured, clear, and pure gemstones to a very inferior and impure product. The clear blue varieties are called *sapphires*, the white and yellow ones are *white* and *yellow sapphires* respectively; the red ones are *rubies*; a stone of a turbid magenta hue is *barkleyite*; a purple variety is the *oriental amethyst*, and a green variety is the *oriental emerald*. The gem stones occur principally in river sands and gravels (see *Placers*, p. 133).

The dull-coloured and opaque varieties occur chiefly in India, China, Siberia, and the United States. They are found in the crystalline and metamorphosed rocks in the Salem district of Madras, India, and in several other localities. Large deposits of a grey, red, or purple colour occur near Singrauli in South Rewah. Corundum is also commonly found in gneiss, mica-schist, and hornblende-schist. The American deposits are found principally in North Carolina and Georgia; in the latter, corundum frequently

occurs in association with hornblende-gneiss, in large masses weighing as much as 5000 lb.

Corundum is a natural oxide of aluminium containing up to 97·5 per cent of alumina. Table XIII. shows the composition of various types of corundum.

TABLE XIII.—ANALYSES OF CORUNDUM [1]

	Alumina.	Ferric Oxide.	Silica.	Lime.	Water.
Indian sapphire . .	97·51	1·89	0·8	..	..
Indian ruby . . .	97·32	1·09	1·21	..	..
Indian corundum . .	93·12	0·91	0·96	1·02	2·86
Asia Minor corundum .	92·39	1·67	2·05	1·12	1·60

The varied colours of corundum appear to be due to mineral impurities in some peculiar (possibly colloidal) state. Thus, the colour of ruby may be due to the presence of chromium oxide, as on heating it turns to green but regains its normal colour on cooling. Cobalt has been suggested as the possible cause of the colour of sapphire, though it may, in some cases, be due to chromium.

Corundum is extremely hard, its hardness being 9, according to Mohs' scale, so that it is very valuable as an abrasive. For this purpose it is crushed and graded in the same manner as other abrasives and made into abrasive papers, cloths, wheels, etc. It is also much used in lapidaries' work. The abrasive power of corundum, as compared with that of pure sapphire and emery, is as follows :

Sapphire	100
American corundum . . .	90-97
Naxos emery	40-57

Emery is an impure variety of corundum which is also used as an abrasive, but it is not quite so hard as corundum (see also *Emery*, p. 101).

Artificial corundum is made by fusing calcined bauxite in an electric arc furnace. Emery may also be used, but charcoal or coke must be added to reduce the iron compounds present to the metallic state. The process is simple, yet by no means easy to work profitably, on account of the very powerful electric currents employed and the exceedingly high temperatures (far above that required in steel manufacture) which are attained. The furnace consists of a square or circular chamber which may be built of fire-bricks covered with sheet iron which is kept cool by water flowing over it. If fire-bricks are omitted and the mixture to be

[1] Thorpe's *Dictionary*.

heated forms its own "crucible," the chamber must be large, as the part of the charge of bauxite nearest the walls acts as a container. In the centre of the chamber are two or three carbon electrodes or rods which carry the current; they are mounted on rack-work in such a manner that the lower end of one rod can be made to touch that of the other or can be kept at any desired distance from it. At the bottom of the chamber are placed several pounds of iron or steel turnings, and the two lower ends of the electrodes are brought into contact with these. If the current is then switched on, an arc is formed and the iron is rapidly melted. Before complete fusion occurs, bauxite is shovelled into the furnace in small quantities at a time and at such a rate as to make the best use of the heat developed by the electric arc. When the temperature of the bauxite is about 2200° C. it melts, and, owing to the highly reducing action of the arc flame, any iron compounds present are reduced to the metallic state. As fusion proceeds, the material becomes so intensely hot that most of the silica is volatilised and so escapes. Finally, the metallic iron settles to the bottom of the furnace, and the molten alumina occupies a central position with a light slag, due to various impurities, above it, and unfused bauxite all around. From time to time the molten iron may be run off, but with an almost pure bauxite there will not be sufficient iron to permit this. When no more alumina can be fused in the furnace, the current is switched off and the furnace is allowed to cool. The current is usually alternating. It may be supplied at 110 volts and 300 amps., which is equivalent to about 700 h.p. per "run," but for larger furnaces 6000 amps. and 100 volts are used.

When cold the contents of the furnace are removed and sorted according to their various natures, the central mass of fused alumina (which during cooling should have been largely recrystallised) being the desired product.

In order to obtain a satisfactory abrasive material, large furnaces must be employed, and at the Norton Company's works masses of corundum each weighing 5 tons or more are regularly obtained. When such large masses are cooled they develop cleavage planes, and by taking note of these the crushing is facilitated. In the best type of furnace the hearth can be gradually lowered during the fusion, and by this means a much larger quantity of alumina can be fused than when a fixed hearth is used.

The more slowly the product cools, the better will be the crystals and the greater the toughness and abrasive power of the product. Hence, by regulating the temperature and the rate of heating and cooling, the hardness and toughness of the mass and the angularity of the particles formed when it is crushed can be varied. By this means a product with different "tempers" is secured.

An alternative method—patented by G. Dollner in 1897—consists in igniting a mixture of metallic aluminium with various

oxides, whereby the product attains so high a temperature that partial fusion of the resultant alumina occurs.

Adamite is a dark blue material approaching black in colour, and contains about 80 per cent of alumina.

Aloxite is an artificial corundum having a highly crystalline structure and a purplish blue colour, made in the south of France and at Niagara Falls, America.

Alundum is an artificial corundum made by the Norton Company, Chippawa, Canada.

Borocarbone is an aluminous abrasive made in France.

Corubin is a by-product of the Goldschmidt "Thermit" process of making chromium, and consists of a crude form of fused alumina which occurs in the slag.

Oxyalumina is an abrasive made in America by fusing aluminous earths.

Cretaceous Sands, see also *Greensand* (p. 118) and *Wealden Sands* (p. 168).

Diamond is the hardest mineral known in nature, having a hardness of 10, according to Mohs' scale. It is found in sand and gravel deposits formed by alluvial action, and also in alluvial beds, which have later been covered by more recent deposits of rocks (see *Gem Gravels and Sands*, p. 112).

Diamonds are chiefly used as gem-stones and as abrasive materials, the largest and purest stones being selected for gems. The less valuable diamonds and the powder obtained by crushing them are used by lapidaries for cutting and polishing other diamonds and precious stones. The powder is also embedded in a disc of soft iron, and used for cutting ornamental stones and for preparing thin sections of rocks.

Inferior varieties of carbon, including *carbonado* or *black diamond* (p. 91) and *bort* or *boart* (p. 84), are also used as abrasives, carbonado being used in the steel crowns of rock-drills.

Diatomaceous Earth (sometimes known as **Barbadoes Earth** and as **Kieselguhr**) is a highly siliceous sediment or deposit produced by the accumulation of extremely minute plants called "diatoms," having an external casing of silica. In time, countless millions of these microscopic siliceous shells form a bed of a light porous nature, varying in colour on account of various inorganic impurities which may be present. The deposits are usually contaminated with other materials which have been deposited simultaneously, the principal impurities being silt, clay, sand, volcanic ash, and decayed vegetable matter. With the exception of the organic matter, which is destroyed by calcining the material, these impurities cannot be separated cheaply, and therefore adversely affect the value of the kieselguhr. There are, however, very pure beds, which contain 95 per cent and more of silica, in Germany, Norway, the United States, Italy, and near Algiers.

The German kieselguhr is obtained chiefly from Naterleuss, between Hamburg and Hanover, where a deposit 150 ft. thick

occurs, its colour varying from white at the surface, where it is associated with a coarse sand which can be removed by washing, through a bed of grey material containing less sand and enough carbonaceous matter to calcine the material, to the lowest bed, which is 50-100 ft. thick and consists of green kieselguhr containing up to 30 per cent of carbonaceous matter. Important deposits from which large supplies have been obtained also occur at Oberhohe.

The Algerian beds are amongst the finest in the world, though, as yet, they have not been fully exploited.

Enormous beds occur at St. Lucian, sometimes attaining a thickness of 150 ft., the better qualities occurring near the bottom of the deposit.

Other smaller or less pure deposits occur at Auxillac in France (p. 98), Spain, Ireland, and Scotland. The Irish kieselguhrs are highly coloured, very impure, and of limited usefulness.

In Scotland, a diatomaceous earth occurs in Skye and Aberdeenshire. In the north of Skye at Loch Cuithir the deposit is 40 ft. thick and consists of material which, when air-dried, contains 94·4 per cent of silica and 4·43 per cent of water, so that if all the water were removed it would contain 98·78 per cent of silica. Diatomaceous earth also occurs in Loch Mealt, Sartil, Loch Cleat, Loch Snuisdale, and Glen Uig, in the Isle of Skye. In Aberdeenshire it occurs near Ballater and contains about 83 per cent of silica, 5·5 per cent of iron oxide, 2·1 per cent of alumina, and 2·93 per cent of magnesia.

Diatomaceous earths have also been found at North Tolsta in Lewis, where it is 7½ ft. thick, Loch Ba in Mull, where it varies from 1 to 2 ft. thick, and at one end of Loch Leven in Fifeshire, where it is about the same thickness.

Most of the best known beds of kieselguhr belong to the Tertiary epoch.

The colour of kieselguhr varies considerably and does not indicate the quality of the material. In some cases the colour of the dried earth is much better than that of the freshly dug material. As a general rule the lighter deposits are preferable to the more highly coloured ones, and the best qualities yield an almost pure white or cream-coloured material when calcined. The analyses given in Table XIV., and due to A. Bigot, show the composition of kieselguhr from various sources.

In its pure state kieselguhr contains 25-45 per cent of moisture, which is expelled at 100° C., leaving a very light, soft, easily abraded material. Under the microscope the regular forms of the plant skeletons are readily seen, some of them being very beautiful and characteristic. The form of silica found in these skeletons is very peculiar, being an irreversible colloidal gel containing 5-10 per cent of combined water, which is evolved on heating to redness. In the raw earths there is usually a variable proportion of reversible silica gel. These two forms of silica are easily attacked

by hydrofluoric acid, and are soluble in solutions of sodium carbonate of all strengths.

TABLE XIV.—ANALYSES OF KIESELGUHR

Composition.	Lunebourg.	Auxillac.	St. Denis Le Sig.		Lompoc, California.		
			A.	B.	A.	B.	C.
Combined water	5·26	3·5 }	6·4	5·2	5·54	5·57	2·22
Organic matter	8·43	3·0 }					
Silica	81·25	88·90	74·0	86·5	88·78	85·28	94·59
Alumina	3·19	2·65	1·99	1·35	2·68	5·35	1·87
Ferric oxide	1·34	1·5	1·06	0·50	Trace	1·12	0·76
Titanium oxide	0·15	0·26	..	..	0·10	0·21	0·10
Lime	0·18	0·20	6·61	2·95	1·61	1·12	0·83
Magnesia	0·20	0·15	1·58	0·75	1·30	1·30	Trace
Alkalies	..	..	2·16	0·40	..	..	..
Carbon dioxide	..	..	6·20	2·70	..	..	..
					White	Brown	White compact shale.

On heating the kieselguhr to 600°-700° C. in a current of air, the combined water is driven off and the organic matter burns away, so that, whilst the appearance and volume of the earth remain unchanged (except for the colour), its power of absorption of gases and liquids is increased and it becomes harder. When heated between 700° and 1000° C., these earths contract and increase in hardness and apparent density. The cubical contraction increases fairly uniformly with the temperature of calcination, a block with a volume of 100 c.c. at 700° C. shrinking to about 25 c.c. at 1400°-1600° C. The apparent density—or strictly the volume-weight—remains constant at 0·5-0·7 below 700° C., rises rapidly to 1·4 at 1000°-1400° C., and steadily increases to about 2·2 at 1400°-1600° C., between which temperatures the material fuses. The true specific gravity is about 2·6 below 1000° C., but at the fusion point it falls to 2·22-2·25. About 77-80 per cent of the total volume of dried material consists of air enclosed in the cells, this proportion of voids being 6-8 times that of lightly calcined clay.

The normal melting point of kieselguhr is 1570°-1600° C., but it is sometimes as low as 1300° C. in very impure earths.

Kieselguhr possesses certain catalytic properties similar to, but less marked than, those of freshly deflocculated china clay.

The thermal conductivity of the calcined material is proportional to its volume-weight, and is very low on account of the large proportion of voids or air-spaces in the mass. Consequently, it is of great value as an insulator. Its heat-conducting power, as compared with other materials, is shown in Table XV. (by Harvard).

TABLE XV.—THERMAL CONDUCTIVITY OF INSULATORS

Material.	Temperature of Burning. °C.	Thermal Conductivity gm. cal. per sq. cm. per cm. per 1° Diff.
Kieselguhr	..	0·0018
Fireclay brick	1300	0·0050
Bauxite brick	1300	0·0033
Silica brick	1300	0·0031
Magnesia brick	1300	0·0065
Carborundum brick	1300	0·0145
Chromite brick	1300	0·0034
Graphite brick	..	0·024
Building brick	1050	0·0037
Porcelain	1400	0·0046

At 2000° F. (1093° C.) a layer of raw kieselguhr of 1 in. in thickness is equivalent to 6·5 in. of good firebricks, or 1·35-1·65 in. of magnesite bricks.

The specific heat of kieselguhr resembles that of clays and other ceramic materials and averages about 0·25, so that a compacted mass of the material, with a volume-weight of 0·5, absorbs $2\frac{1}{2}$ times as much heat as the loose powder with a volume-weight of 0·2, whilst a fireclay brick with a volume-weight of 1·8 will absorb nine times as much as the powdered earth.

The chief uses of kieselguhr and other diatomaceous earths depend on their lightness and porosity, for which reason they are used (*a*) as heat insulators, (*b*) as refractory materials, (*c*) as absorbents, and (*d*) as fillers.

As a heat insulator they are very valuable, and are employed for covering steam-pipes and boilers, for safes, fireproof rooms, and for filling the bulkheads of steamships, etc. Such earths are of great value in many situations where both refractoriness and heat-insulating properties are desired, but, on account of their great porosity, they are of little use for resisting the corrosive action of slags and fluxes, and should not be used in exposed positions in furnaces, but only as an intermediate walling, *i.e.* where their surface is protected by firebricks or other slag-resisting material on the one side and from the weather on the other. In such cases they are very valuable, and are largely used for covering the crowns of kilns and furnaces of various types, and as an intermediate walling in boiler settings, blast furnaces, etc. A tunnel kiln efficiently insulated with kieselguhr on the sides and roof can usefully employ 98 per cent of the available heat in the fuel, the outside walls having only a temperature of 28° C. when that of the inside walls is 1250° C.

Kieselguhr has been used as an absorbent for bromine for disinfecting purposes, and for sulphuric acid. "Dry sulphuric acid" is kieselguhr saturated with 3-4 times its weight (*i.e.* about

75 per cent) of sulphuric acid; it forms a loose powder which can be shipped or transported with far less risk of loss or damage than is the case when the liquid acid is sent in containers.

Kieselguhr is used in the manufacture of ultramarine and as a filler in the production of soap and cotton, and rubber fabrics. It is also employed in compositions used for preventing rot and fungus. It is a mild abrasive, and is used for polishing metals, and as a tooth powder. It is also used for making imitation meerschaum, in the preparation of paints, as a filtering agent, and also in the manufacture of sodium silicate (water-glass), as it is easily acted upon by alkalies.

For use, the kieselguhr is dug in such a way as to produce rough blocks, which are stacked in the open and left until they contain only 15-25 per cent of water. The half-dry material is then taken to the grinding plant, where it is reduced to powder and may be dried still further by passing warm air through the grinder. Artificial drying does not appear profitable, though in California the blocks are exposed to the air for 40-50 days, then sawn into bricks; the drying is completed in kilns. If calcined kieselguhr is required, the grinding may be postponed until after calcination.

The calcining is usually effected in small round kilns, but where the output is sufficiently large a continuous shaft kiln is much more economical. *Tripoli* and *Moler* are materials somewhat resembling kieselguhr, and are dealt with under their respective headings.

Diatomaceous Ooze is a siliceous deposit found in the Arctic and Antarctic regions, especially the latter. It contains a fairly large proportion of mineral matter deposited by ice, and also has a variable proportion of calcareous matter, such as foraminiferae, but other organic materials are very rare. It is of a similar nature to the diatomaceous earths found above sea-level, and, when dry, is of a white or yellowish colour, very similar to tripoli or kieselguhr.

Diluvial Sands are deposits formed by the action of powerful streams, floods, or other unusual action of water. They are extremely variable in composition and may contain, in addition to what is usually termed sand, considerable proportions of gravel, chalk, limestone, and other impurities. Their value and uses depend upon their chemical composition and physical nature. These sands must not be confused with those produced by the *normal* action of water, which are termed *alluvial* sands.

Dinas Sand is a pale yellow material produced from the disintegration of the famous Dinas quartzite deposits occurring in the Vale of Neath, Glamorganshire. The best samples of the material contain 98 per cent of silica, 1 per cent of alumina, and 1 per cent of iron and other oxides, but a more average composition is:

Silica	95 per cent.
Clayey matter . . .	4 ,,
Fluxing oxides . . .	1 ,,

Dinas sand is largely used for the manufacture of silica bricks; some of these have a world-wide reputation. (See also *Quartzites*, p. 138.)

Dolomite Sands are deposits caused by the weathering of dolomite limestone; the calcareous material, being soluble in water containing carbon dioxide, is removed in solution, leaving the more magnesic material behind, together with more or less silica sand. In the Paris basin a limestone has been weathered in this way, leaving a dolomitic sand in which are embedded nodules of unaltered limestone, locally known as *têtes de chat.*

Drift is a general term for deposits of detrital materials, and may be formed as a result of aeolian, fluviatile, estuarine, marine, or glacial action. More often it is applied to deposits formed as a result of glacial action. For special kinds of drift sands see under *Blown Sands* (p. 82) and *Glacial Sands* (p. 115).

Eluvial Sands and Gravels are deposits of loose aggregated material formed by the action of weathering agencies on the rocks below them, and should not be confused with alluvial sands, which are produced from the same materials, but have been transported from their places of origin and deposited elsewhere.

Emery is not a natural sand, but in the powdered state it is used so largely as an artificial sand as to be suitably included here. It occurs as a greyish, impure variety of corundum, which consists of crystalline or granular corundum mixed with a greater or less proportion of iron oxide, chiefly in the form of magnetite and various other accessory minerals, including tourmaline, hercynite, garnet, muscovite, diaspore, kyanite, rutile, etc.

At one time emery was obtained almost entirely from the island of Naxos, in the Grecian Archipelago, where it occurs in blocks embedded in the soil and also in the crystalline limestone of the islands. It is now found in Asia Minor, especially near Ephesus and Philadelphia, where it is also partly obtained from the loose soil and partly as a rock which has to be mined.

It is also mined in the United States at Chester (Massachusetts) and Peekskill (New York).

Table XVI.[1] shows the chemical composition of the three chief varieties of emery.

TABLE XVI.—ANALYSES OF EMERY

Source.	Alumina.	Magnetic Iron Oxide.	Silica.	Lime.	Water.
Gumach . .	77·82	8·62	8·13	1·80	3·11
Naxos . .	68·53	24·10	3·10	0·86	4·72
Samos . .	70·10	22·21	4·00	0·62	2·10

[1] Thorpe's *Dictionary*.

The specific gravity of emery varies slightly in different localities. The Samos emery has a specific gravity of 3·98, that from Gumach is 3·82, whilst the Naxos emery has a specific gravity of only 3·75.

The emery is first broken by sledge-hammers or powerful crushers. Sometimes, prior to breaking, the emery is heated and quenched in water or cooled with a blast of air, so as to cause strains in the material which facilitate fracture. The broken stone is examined, and any useless material picked by hand; the residue is then crushed, washed, and sifted. The smallest particles are still further purified by elutriation with water, and are thus separated into various grades.

Emery is chiefly used as an abrasive, its hardness depending on its internal physical structure and the manner in which the particles are aggregated together. According to L. Smith, the texture is of greater importance than the proportion of alumina present.[1]

The hardness of various samples of emery as compared with sapphire is as follows:

Sapphire	100
Gumach emery	47
Naxos emery	46
Samos emery	56

Emery is used in the form of emery-cloth, emery-paper, emery-sticks, etc., the powder being glued by some suitable medium to the backing or support. It is also used in the form of wheels, made by mixing the powder with a binder such as shellac, moulding the mixture into the desired shape, and afterwards heating the articles in a stove until they are sufficiently hard. In some cases emery is bound with a paste consisting of loam and water, but such a product would not be suitable for grinding wheels unless the loam were of an unusually plastic nature and so fusible that, on heating the mixture in a kiln, the loam formed a fused or vitrified bond. As loams are variable in composition, artificial mixtures of china clay and felspar are generally substituted when vitrified emery wheels are to be produced.

Eocene Sands, see under subdivisions, *Barton Sands* (p. 82), *Bagshot Sands* (p. 81), *Bracklesham Sands* (p. 84), *Woolwich and Reading Sands* (p. 168), *Thanet Sands* (p. 163). Other Eocene sands of lesser importance are dealt with on p. 66 in Chapter II.

Eskers are winding ridges of sand and gravel, the material being sometimes irregularly stratified. They appear to be the beds of streams which flowed in or beneath a glacier and were left when the ice melted.

Estuarine Sands (sometimes termed "muds") are produced by the precipitation of finely divided fragmental material carried down by rivers to the sea. Some of the finest particles of material

[1] *Amer. Journ. Science*, 1851, ii. 366.

in water are in a state of colloidal suspension, and they ren in this state on account of the repelling action of the electrical charge of each particle. Coarser particles are sometimes kept in suspension by being surrounded by colloidal matter. When the suspended particles come into contact with the saline matter in the sea-water, the charges on them are released and, as a result, the particles are flocculated and form larger masses, which settle in the bed of the estuary. For this reason, some fine material settles quite close to the shore, whereas in the ordinary way fine particles produced by coast erosion are carried much farther out to sea.

Estuarine sands consist chiefly of very small particles. They are frequently laminated, because changes in the speed of the river have caused materials of different degrees of fineness to be laid upon one another. Lamination is also accentuated in tidal flats by the constant covering and uncovering of the deposit by the moving water. Whilst silica is the chief constituent of estuarine sands, clay is often present, together with a very variable proportion of calcium carbonate and organic matter. In some cases, as in the Medway and Thames in England, and in the Seine in France, these calcareous muds are valued for the manufacture of cement, provided they contain sufficient clay.

The occurrence of estuarine sands in the Oolitic formation has been previously described on p. 59. These sands consist for the most part of very fine grains of different colours, the beds, on account of their fluviatile origin, being very variable and of limited extent. They vary in colour from almost pure white to brownish.

At Huttons Ambo occur beds of various colours from cream to yellow and brown, the upper ones containing clay and grey carbonaceous matter. They contain, according to Boswell, about 84 per cent of silica and 9 per cent of alumina, together with about 1·6 per cent of iron oxide. The lower beds are much purer, containing only about 0·13 per cent of iron oxide, of which 0·09 per cent can be removed by washing.

At Denford (Northamptonshire), according to Boswell, the cream-coloured Oolitic sand contains about 98 per cent of silica and 0·06 per cent of iron oxide, whilst at Tadmarton the iron content is somewhat higher.

The impurities present consist chiefly of ilmenite and other iron-ores, garnet, zircon, rutile, kyanite, tourmaline, glauconite, staurolite, muscovite, and anatase. Serpentine also occurs in the Huttons Ambo beds. The proportion of impurities is generally fairly low; Boswell found a total of 0·5 per cent or less impurities in the ones he examined.

Large portions of the beds at Huttons Ambo are quite uniform in texture; according to Boswell, about 85 per cent of the grains are between 0·25 and 0·5 mm. diameter, and about 7·5 per cent between 0·1 and 0·25 mm. diameter. At Tadmarton the beds are similar to those at Huttons Ambo in texture, about 80 per

cent of the grains being between 0·25 and 0·5 mm. diameter, but at Denford the sand is much finer; Boswell found that most of the grains in the Denford sand were between 0·1 and 0·25 mm. diameter. This sand is cream in colour, turning to pinkish when burned.

The Estuarine sands are used for various purposes. The best qualities from Huttons Ambo and Denford are suitable for glass manufacture, whilst the more highly coloured ones (particularly the upper beds at Huttons Ambo, which contain a notable quantity of clayey matter) are used in steel works and foundries for moulding purposes.

Some of the better qualities at Huttons Ambo are also used for the hearths of open-hearth furnaces.

Facing Sand is a specially prepared sand which is used to give a smooth face to the sand-moulds used for casting metal in foundries. It is shaken on to the pattern through a sieve and is afterwards rammed until it has a thickness of about one inch. (See Vol. II. Chapter VI.)

Ferruginous Sands are, as their name implies, those rich in iron compounds.

Fire-sand is an artificial sand produced in the manufacture of carborundum. (See *Carborundum*, p. 86.)

Fluviatile Sands (or **River Sands**) are those found on the banks and beds of rivers, streams, etc., and in situations where ancient streams existed (see p. 28). They usually consist of sharp angular grains, very variable in size and composition, but excellent for mortar, concrete, etc., where the grains are required to interlock with each other. They are also useful for filter beds.

The fluviatile sands in the Thames, near Woolwich, are recovered by dredging, and used as moulding sand for brick-making. Fluviatile sands are seldom sufficiently pure or uniform in size of grain to be used for glass-making.

Foraminiferal Sands are calcareous deposits of the skeletons of marine organisms formed chiefly on deep floors of the sea in different parts of the world (see p. 35). They are only of scientific interest and have no commercial value. Sands composed of other marine organisms also occur in similar localities (p. 35).

Fusible Sands are those containing a large proportion of fluxes, such as lime, soda, or potash, in the form of felspar, mica, or other fusible minerals. A high proportion of iron compounds also reduces the refractoriness of sands if they are heated in a reducing atmosphere.

Ganister is a slightly plastic, fine, siliceous grit, containing up to 10 per cent of clay and forming a compact bedded sedimentary rock of very fine granular texture.

The origin of the term "ganister" is unknown, but it was first applied, in connection with steel furnaces, to the fine dust carefully collected from the country roads between Sheffield and Penistone, which was rightly regarded as of great value on account

of its refractoriness. As the demands for this material increased much faster than the supply, attempts were made to produce a similar material by grinding the rocks used in making the roads. Laborious investigations eventually led to the recognition of certain outcrops of fine-grained silica rocks as being the most suitable for furnace linings, and the term ganister was therefore transferred to these rocks. Since then the term has been extended (unwisely, in the author's opinion) to other silica rocks, some of which are quite unsuitable for furnaces, and this has led to much loss and disappointment. As, originally, the term "ganister" was applied to rocks of a certain geological horizon, viz. that immediately below the Ganister Coal in South Yorkshire and Lancashire, it seems desirable to confine it to these rocks. The use of the term "ganister" for fine-grained silica rocks which lie just above the Millstone Grit in other coalfields is open to objection, as the properties of such ganisters are not identical with those of the "true ganister" of South Yorkshire. The still wider use of the term to include siliceous rocks from other geological horizons should be avoided as being incorrect and misleading, even though such rocks are used for some of the purposes for which true ganister is employed.

The term "true ganister"—when used in this volume—is strictly confined to the fine-grained siliceous rocks which lie immediately below the Ganister Coal; other similar rocks are termed "bastard ganisters."

True ganister is extremely hard and difficult to crush, whilst some other rocks sold as ganister may be reduced with comparative ease to the constituent grains of sand, of which they are almost wholly composed. The best ganister appears to be associated with an underlying fireclay.

Only a small part of the so-called ganister group of rocks is of value commercially, as the remainder is too impure to be used as a refractory material. The outcrops of ganister are specially sought, as they enable the material to be obtained more readily than from the deeper portions of the same beds. The materials from the outcrop are often purer than those obtained from a greater depth below the surface.

The desirable features in ganister used for the manufacture of ganister or silica bricks and for lining furnaces are:

1. The angularity of the grains.

2. The evenness or uniformity of the grain size. The best ganister rocks consist of grains 0·1-0·3 mm. diameter.

3. The interlocking of the mass. Rocks with rounded grains are generally less pure, less compact, more friable, and more likely to have received infiltrated impurities. When the cementing material is wholly siliceous, the close interlocking of the grains is not so important.

4. The presence of only a small quantity of interstitial matter.

Table XVII. gives figures which are typical of the ganister obtained from the chief sources of this material.

TABLE XVII.—ANALYSES OF GANISTER

	Durham Ganister.	Hard Ganister.	Sheffield Ganister (Lowood).	Sheffield Ganister (Holling).	Bonnymuir Ganister.	Laisterdyke Ganister.
Silica	97·2	97·9	88·4	97·8	89·2	97·0
Alumina	1·5	0·6	6·4	0·2	4·0	1·5
Ferric oxide	0·5	0·3	1·7	0·2	2·6	0·8
Lime	0·3	0·6	0·7	0·4	0·4	..
Potash	0·5	..	..	0·2	0·4	0·5
Magnesia	..	0·2	0·4	0·4	..	..
Water	..	0·4	2·4	0·7	3·4	..

The occurrence and distribution of the ganister rocks of South Yorkshire have been described on p. 49.

The Sheffield ganister—which is the best known and the most widely used—varies from a pale grey to buff colour, the predominant shade being a pale grey. It has an almost constant composition, averaging 97·7 per cent of silica, about 0·35 per cent of alumina, and about 0·14 per cent of potash and 0·28 per cent of soda, with practically no carbonates, and a very low percentage of hydrous silicates. The great superiority of the Sheffield ganister depends on its physical properties rather than on its chemical composition. Its fracture is similar to that of chert; when ground, it breaks into granular fragments, which interlock readily under slight pressure and can easily be compacted into a strong mass. The grains are irregular in shape and are very small, generally between 0·05 and 0·15 mm. diameter. A small proportion of clay is present and some of the grains are usually united by a siliceous cement. Sericitic mica is abundant, particularly in the thicker parts of the beds, and iron stains are frequent, though irregularly distributed, some portions of the deposits being almost free from iron compounds. Felspar is rarely found, but occurs in some ganisters. Plant-remains and carbonaceous streaks are very common, but do no harm to the material.

Towards Huddersfield and Leeds the ganister rock is softer and contains more clayey matter. The texture is somewhat coarse, the grains being generally between 0·05 and 0·2 mm. diameter. The fracture of the rock is less cherty and the grains produced by grinding are less angular than in the Sheffield ganister, so that they do not produce such compact linings to furnaces nor such good bricks. Titanium oxide occurs fairly abundantly, as rutile, anatase, and brookite. The rocks also contain more felspathic material and white mica than in the Sheffield ganister. Iron compounds are comparatively common in the cement.

In Derbyshire the ganister rocks are more siliceous and some-

what coarser. At Ambergate the grains vary in size between 0·1 and 0·3 mm. diameter, and a small proportion of heavy detrital minerals is present.

In North Lancashire the ganister is somewhat similar, but much inferior to the Sheffield material, and generally contains less than 85 per cent of silica. At Rishton the texture is very fine, most of the grains being about 0·03 mm. diameter, though some are as large as 0·1 mm. diameter. Flakes of white mica are disseminated through the rock, and various heavy minerals, including iron-ores, rutile, and tourmaline, occur in the interstitial cement.

In the Accrington district ganister of rather better quality occurs, and is known as Warmden rock; it contains about 90 per cent of silica, 6 per cent of alumina, and less than 1 per cent of iron oxide. In South Lancashire the rock is light to dark grey in colour, but it is much streaked by carbonaceous matter and plant-remains, and contains, on an average, about 88 per cent of silica and 7-8 per cent of alumina. In texture it is generally very fine, the grains averaging 0·1 mm. diameter, though some parts are composed principally of grains about 0·05 mm. diameter. The cement is partially siliceous, but there is also an appreciable amount of clay, as shown by the percentage of alumina; in some places its composition approaches that of fireclay. Mica and other impurities occur in small proportions.

Bastard ganisters are often used in place of the true ganister, and whilst they resemble the latter in chemical composition, they do not possess the same physical texture, and the use of the term ganister in connection with them is best avoided. They may be termed "silica rocks" or "sandstones."

It is difficult to distinguish some of the bastard ganisters from the true ones with the unaided eye, as both may be fine-grained and contain abundant traces of fossilised roots and other remains of plants. The difference is readily seen when a thin section of the rock is examined under the microscope.

The principal bastard ganisters occur in Durham and North-Eastern Yorkshire, South Wales, Lanarkshire (Scotland), and at Ballyvoy, near Ballycastle (Ireland). Their distribution has been described in Chapter II.

The *Carboniferous Limestone Series* contains several bastard ganisters, particularly the "pencil-ganister" and the "Egglestone ganister."

The pencil-ganister of Durham and North Yorkshire consists of a greyish fine-grained rock, streaked with carbonaceous matter. In some places, as at Wensley, it has a pinkish tinge, and at Rookhope the upper bed is so darkened by carbonaceous matter that it is termed black pencil-ganister. The beds contain a fairly high proportion of silica, those at Rookhope having from 97·5 to 98 per cent. The texture is generally fine, the grains being from 0·1 to 0·15 mm. diameter, the Wensley rock being rather finer than that in the beds at Rookhope.

The black pencil-ganister of Rookhope is very similar to, though not quite so fine as, the Sheffield ganister, and is probably one of the nearest approaches to true ganister in the district.

The Egglestone ganister, which occurs at Consett, Co. Durham, consists of two beds of dirty white or greyish quartzitic sandstone, the upper bed being rather coarser than the lower and consisting chiefly of grains up to 0·15 mm. diameter. In the lower bed the grains are chiefly between 0·05 and 0·1 mm. diameter. The cement, though largely siliceous, is rather impure, and abundant detrital minerals occur. The upper bed is ferruginous in parts, whilst mica is common in the lower bed. It is mixed with other silica rocks for use in the manufacture of silica bricks.

At Daddry Shield the ganister is pale buff in colour and very fine-grained, consisting chiefly of grains up to 0·1 mm. diameter, though a few may be as much as 0·3 mm. diameter. Heavy detrital minerals are fairly abundant; mica is present in small proportions, but felspar is absent. It is used for silica brick-making and, with the addition of clay, for ganister bricks.

In Scotland, bastard ganisters occur in the Carboniferous Limestone Series in Peeblesshire and Lanarkshire. In Peeblesshire they vary from pure white to dark grey on account of the presence of carbonaceous matter. They consist of almost pure silica, the rock at Cairn Burn containing 98·45 per cent, and that at Deepsykehead 99·44 per cent. They contain practically no felspar or mica, though ferruginous and titaniferous impurities are sometimes common. These rocks are very refractory (Cone 36-37). Their texture is very fine-grained, the particles generally being about 0·1 mm. diameter.

In Lanarkshire the rocks are rather coarser and more micaceous. In some parts they also contain a considerable amount of calcium carbonate, which forms part of the interstitial cement.

In the *Millstone Grit Series* the bastard ganisters occur chiefly in Scotland. Those mined at Bonnybridge consist of light-coloured and somewhat micaceous sandstones, containing 91-96 per cent of silica, 0·26-0·30 per cent of alkalies, and 0-0·45 per cent of lime. Felspar occurs in small quantities in some of the beds; minute particles of mica are, in places, abundant. They are usually very fine-grained, consisting of particles from 0·075 to 0·1 mm. diameter, cemented by siliceous and argillaceous material.

The Scottish ganisters are used chiefly for making bricks, and as ground ganister for steel furnaces.

The bastard ganisters of the Millstone Grit Series in Cumberland consist chiefly of thin yellowish-white or pale grey laminated sandstones, usually quite soft and friable, and generally containing some felspar and mica. Clay occurs in the cement, together with heavy detrital minerals. At Branthwaite the cement is partially calcareous and dolomitic. Carbonaceous matter occurs in all the beds. In texture they are usually fine-grained, the particles

varying in size from 0·1 to 0·2 mm. diameter. At Workington mos of the grains are less than 0·1 mm. diameter.

The *Crowstones* of Cheshire consist chiefly of a hard, brittle, bluish-grey or buff rock; in some parts they resemble Sheffield ganister, but are much coarser. At Mow Cop, Cheshire, this material is pale buff in colour and consists of grains from 0·1 to 0·2 mm. diameter. A few particles of chert occur, but no felspar. The Congleton bastard ganister is very similar to the Mow Cop rocks, but felspar is of more frequent occurrence.

Ridgeway bastard ganister is pale yellowish-grey and very fine-grained (0·005 mm.). Detrital minerals, especially zircon and tourmaline, are fairly abundant, and iron compounds also occur in small proportions. It is very similar to the Durham bastard ganisters, but is not so compact as that in the Sheffield district.

Litchfield ganister is similar to that at Ridgeway, but is more micaceous, abundant flakes of muscovite mica being present.

A bastard ganister occurs in the Cefn-y-fedw sandstone at Trevor, near Ruabon, called the Chwarele ganister. It is greyish and consists of grains between 0·05 and 0·1 mm. diameter, associated with heavy detrital minerals, clayey matter, and sometimes with mica.

The so-called ganisters of the Lower Coal Measures of Durham are really bastard ganisters; they have a rather larger proportion of impurities and of alumina than the true ganisters of the Sheffield district. None of these "ganisters" possess the same fineness of grain or such density and hardness as the blue and black ganister of South Yorkshire, though portions of the rocks possess somewhat similar characteristics.

The Durham bastard ganister consists generally of a pale grey, fine-grained sandstone, the grains varying in size from 0·05 mm. diameter to 0·15 mm. diameter (average about 0·1 mm.). In places they are iron-stained, though generally the iron content is low. The proportion of interstitial cement is usually small; it is chiefly siliceous, and the impurities include felspar, mica, zircon, rutile, and brookite, in addition to iron compounds and carbonaceous matter. Felspar is generally present in only small quantities, but mica is sometimes abundant, as at Knitsley Fell, Crook, Consett, and Stanhope. Some parts of the beds are very free from impurity, especially at Crook, where it consists almost entirely of pure silica. At Hamsterley, to the south of Wolsingham, the cement is highly ferruginous in some places, though in other parts of the same bed it is siliceous.

The pencil-ganister occurring in the same beds at Crook, Hamsterley, and Knitsley Fell is a white or pale grey rock of fine texture, most of the grains being less than 0·1 mm. diameter; the cement is chiefly siliceous and encloses a small quantity of iron and titanium compounds and carbonaceous matter. Iron compounds are concentrated along the joints, giving local iron staining. Mica is moderately abundant at Crook.

The ganisters in this district are chiefly used for silica brick manufacture, and to some extent for "ganister-mixture" for use in steel works.

Glossop's ganister (Ambergate) is a bastard ganister of a bluish-white colour with very fine grains (0·05 mm. diameter), containing a considerable proportion of ferruginous matter and muscovite mica. It is much iron-stained along the joints of the rock.

The bastard ganister in the Forest of Dean is yellowish in colour on account of the ferruginous matter; it is quite soft and consists of grains up to 0·3 mm. diameter, coated with clay and deeply iron-stained. In the same bed occurs a harder and finer-grained rock, containing more felspar, ferruginous matter, and titanium-bearing minerals, as well as much clay. Both beds are used for ground ganister, which is supplied to iron and steel works.

The *Upper Estuarine Series* has several beds of bastard ganister around Sheffield and in North Yorkshire. Thus, *Castleton ganister*, found at Deepcar, near Sheffield, consists of a nearly white sandstone of fine texture, most of the grains being about 0·15 mm. diameter. It has a considerable proportion of siliceous cement, and in places the iron oxide gives the rock a buff colour. It is used for the manufacture of silica bricks, as a hearth-sand, and refractory mortar.

The *Pencil-ganister* of Commondale consists of a dark grey, rather hard, fine-grained, quartzose sandstone, containing numerous carbonaceous streaks. It is very impure, the cement containing iron oxide and mica. Most of the grains are between 0·05 and 0·1 mm. diameter. It has only been used for the manufacture of silica bricks on a small scale.

The *Hard ganister* at the base of the Upper Estuarine Series consists of a pale buff, moderately hard rock, having an even texture and consisting of grains averaging 0·2 mm. diameter, though some are as large as 0·6 mm. diameter. The cement is a siliceous material containing grains of iron oxide and some tourmaline, but almost free from felspar and mica. This ganister is used principally for the manufacture of silica bricks and also for the hearths of open-hearth furnaces. A softer and reddish bastard ganister, which occurs at some distance below the Hard ganister, is not used commercially.

From the foregoing statements it will be seen that of many silica rocks only a few deposits are commercially valuable as ganister, and that this term relates principally to siliceous rocks having a special texture. This is primarily due to the fine angular grains, surrounded by an almost pure siliceous cement, of which the true ganisters are composed. In other words, the value of ganister is not characterised so much by its geological location, or by the rocks with which it is associated. as by the smallness and angularity of the grains.

Ganister is used for a variety of purposes, but chiefly for lining metallurgical furnaces and as the chief constituent of various

mortars, cements, and "compositions" used in laying firebricks, patching kilns, and for foundry work. *Lump ganister* is the coarsely crushed rock which is only used for rough work. *Ground ganister*—mixed with the requisite quantity of water—can be used in any form of furnace construction which will permit the material being rammed around a pattern or used in the form of a paste. It is largely used in iron-smelting cupolas, Bessemer converters, and crucible-steel furnaces, and as a moulding sand by steel manufacturers. *Ganister bricks* are moulded out of a paste made by mixing ground ganister, lime, and water. *Ganister mixture, pug-ganister*, or *compo* is a mixture of ganister and 5-20 per cent of fireclay; it is used for lining furnaces and for general foundry use, and also for patching and repairing kilns, furnaces, cupolas, etc.

Puramachos is an artificial ganister consisting of powdered quartz, with about 10 per cent of clay and a little water-glass.

Silica cements are made by mixing ganister, silica rock, or other siliceous material with a binding agent such as fireclay or water-glass.

Ganister Sand is a term used for the sands occurring in the pocket clays of Derbyshire. Such sand bears some resemblance to crushed ganister, but is seldom used in the manufacture of pure silica bricks. It is often mixed with clay and used for semi-silica bricks, for which it is very suitable. (See also *Pocket Sands*, p. 134.)

Garnet occurs in cubic crystals having a specific gravity of 3·4-4·3 and a hardness of $6\frac{1}{2}$-$7\frac{1}{2}$. It is generally reddish in colour, though dull green, emerald green, yellow, and black varieties also occur. In composition, garnet is an alumino-silicate of calcium, magnesium, iron, or manganese, or a silicate of calcium and iron, or calcium and chromium, or combinations of any of the above substances. These differences in composition give rise to various kinds of garnets, the chief being almandine, hessonite, spessartite, pyrope, rhodolite, and demantoid.

Almandine is a purplish-red variety found in the alluvial deposits of Ceylon and Minas Novas in Brazil, in the mica-schists of Kirshangarh and Jaipur States of India, and in gneisses, schists, and granites in North America, particularly in the Adirondacks. *Hessonite* is a pale brown or yellowish-red variety found in the gem gravels of Matura district, Ceylon. *Spessartite* is a red or brownish-red garnet which occurs in association with mica in the granites of Amelia in Virginia, U.S.A., and in the gem gravels of Ceylon. *Pyrope* is a crimson garnet found in peridotite and serpentine rocks of Northern Bohemia, and alluvial gravels at Santa Fé in New Mexico and North-Eastern Arizona, where it is known as the "Arizona ruby." In South Africa, where it occurs associated with Kimberlite, it is known as "Cape ruby." *Rhodolite* is a pale red or violet-coloured garnet found with rubies in Macon County, North Carolina, and at Dewalegama in Ceylon. *Demantoid* is a yellow or emerald-green garnet which occurs in serpentine

at Bobrovka in the Ural Mountains, associated with chrysotile asbestos. *Melanite* is a black garnet containing titanium compounds, and is found in syenites and phonolites. *Topazolite* is a honey-coloured garnet.

Small quantities of garnets are very widely distributed, the chief sources being India, Ceylon, the United States, Brazil, Spain, and Russia.

Garnets also occur in Warren Co., New York, associated with hornblende and felspar, from which they are removed by wet concentration. A granite rock containing 40-50 per cent of garnet occurs in Merrimac Co., New Hampshire, together with quartz and biotite mica, from which it is separated by crushing, screening, and dry concentration. In Travancore, India, garnet is abundant in the beach and river sands, whilst in Almeria, Spain, it is also found in alluvial deposits. A typical garnet sand is shown in Fig. 3.

Fig. 3.—Garnet sand. × 20.

The finest garnets are used as gem stones, whilst the inferior varieties are used as abrasives; the latter are chiefly derived from India, Spain, and America.

Garnet is superior to sand as an abrasive, but is inferior to emery in hardness. The powder is used for cutting gems and is also applied to paper, and so used for smoothing woodwork, scouring leather, etc. In North America it largely replaces emery.

Gas Sands are those containing or yielding a natural gas.

Gem Gravels and Sands of great economic importance are produced by the concentration of heavy minerals within a small area by means of the action of water which tends to carry off the smaller particles and those of low specific gravity, leaving a residue rich in the minerals of higher specific gravity. The principal deposits are those containing diamonds, rubies, sapphires, and emeralds.

Diamond beds are the most important of such placer deposits containing valuable gems; they are widely distributed, though in most places the proportion of diamonds is too low to make their recovery profitable. The oldest diamond workings known are in

some of the river gravels of India, particularly at Nizam ıı. Madras presidency, at Sambalpur and Warragarh in the Cer. Provinces, and at Nagpur and Panna in Bundelkhand. These world-famed Indian deposits now contribute little to the present supply.

The South American gem sands in the States of Minas Geraes, Goyaz, Bahia, Matto Grosso, Paraná, and São Paulo form an abundant source of diamonds. In Diamantina they occur in detritus from micaceous sandstones containing quartz and clayey matter with pyrites and tourmaline, but in other localities the diamonds are associated with gold, monazite, rutile, anatase, brookite, magnetite, haematite, ilmenite, etc. In the State of Bahia most of the diamonds are of the carbonado variety.

Africa now provides the greater portion of the world's supply of diamonds, which are obtained partly as gem gravels and sands and partly from mines in intrusive igneous rocks. In the Vaal River basin on the Great Namaqualand coast of South-West Africa the diamonds are scattered through sand and gravel, though in some places they have been concentrated by the action of winds. These deposits consist chiefly of lava, agate, chalcedony, jasper, and quartz. The diamonds occur in association with ilmenite, garnet, zircon, mica, and a banded rock termed " bantam," which is really a spessartite-andalusite rock. On the west coast of Africa, in the bed of the river Jiblong, large quantities of diamonds are found associated with kyanite, corundum, zircon, diopside, rutile, chromite, magnetite, ilmenite, haematite, limonite, pyrites, and gold, these deposits having been derived by the concentration of heavy minerals from disintegrated metamorphic rocks.[1]

The greater proportion of the diamonds in South Africa are obtained by mining an altered basic igneous peridotite, known as " blue ground " and " yellow ground " according to its colour, which indicates the extent of its decomposition, the blue ground being the least weathered. This rock is probably of Lower Cretaceous age; it occurs in large pipes and dykes, the diamonds being associated with serpentine, ilmenite, garnet, diopside, enstatite, phlogopite, picotite, and zircon. The principal pipes are around Kimberley, some being as much as 200 yards wide at the surface, though the width decreases with the depth. They have been worked to a depth of over 3500 ft. The average yield is about 200 milligrams of diamonds per ton of good rock. The yellow ground having been more weathered than the blue ground is easy to work, being quite friable and equally as rich in diamonds. The origin of the Kimberley diamonds is obscure; possibly the carbon was derived from deep-seated basic igneous rocks and crystallised out as the pipes cooled down. Other diamond mines in South Africa occur in Griqualand West, and at Jagersfontein and Koffyfontein in the Orange River Colony.

In Australia diamonds are found in drift gravels on the Cudegong

[1] Hatch, *Geol. Mag.*, 1912, 106.

river, near Mudgei, and at Bingera and Inverell in New South Wales, and rarely at Echunga in South Australia, and at Beechworth in Victoria.

Diamonds are found in association with gold in North Carolina, Georgia, and California, and with platinum in Oregon, and also in an altered intrusive peridotite near Murfreesboro, Arkansas. In British Columbia small crystals are found associated with chromite in peridotite at Olivine Mountain.

In Borneo diamonds are found in alluvial clays, river sands and gravels, and also in an Eocene conglomerate. The gems are associated with corundum, pyrites, gold, and platinum, the matrix consisting chiefly of quartz, together with some fragments of igneous and metamorphic rocks.[1]

For information on the properties and uses of diamonds see under *Diamond*, p. 96.

Rubies and *sapphires* (corundum) usually occur in association with spinel and quartz, and, on account of their highly resistant character, are very often found in river sands and gravels produced by the disintegration of older rocks, and by the concentration of the heavy minerals. Sapphires are found as rolled crystals and pebbles in detrital deposits in Ceylon, and with rubies in Upper Burma. In Ceylon they occur in association with zircon, tourmaline, spinel, corundum, garnet, ilmenite, rutile, chrysoberyl, geikielite, picroilmenite, thorianite, thorite, monazite, fergusonite, and baddeleyite. Cassiterite and gold occur to a very limited extent.[2]

Large sapphires are found in the Zanskar range of the Himalaya Mountains, whilst dark-coloured stones occur in the province of Battambang in Siam.

Rolled sapphires are also found in placer deposits near Helena in Montana, U.S.A., in Brazil, and in the gold drifts of New South Wales and Victoria.

Rubies are distributed less widely than sapphires. The most important source of rubies is Mogok in Upper Burma, where they occur in placers (known locally as *byon*) which have been produced by the disintegration of a white crystalline limestone interfoliated with gneiss. The so-called Australian rubies, Adelaide rubies, and Cape rubies are usually garnets.

Artificial rubies may be made by fusing alumina and red lead together with 2-3 per cent of potassium bichromate in a fireclay crucible. Sapphires are made in the same way, but with the addition of a little cobalt oxide. Gems of superior quality are obtained by fusing small quantities of the same materials in an electric arc, the gems being " built up " as successive layers are fused on to the primary particles. (See also *Corundum*, p. 93.)

Other gems found in sand and gravel deposits include *andalusite*,

[1] *Borneo: Its Origin and Mineral Resources*, trans. from German by F. H. Hatch, London, 1892, p. 385.

[2] *Ceylon Administrative Reports*, 1903–1909.

which is associated with topaz in Brazil placers, *chrysoberyl*, w.... occurs in association with *amethyst*, *tourmaline*, *garnet*, *spinel*, and *topaz* in Brazil and Ceylon, and *cordierite* and *zircon*, which also occur in Ceylon.

Garnets are described separately. (See *Garnet*, p. 111.)

Glacial Sands are really of fluvio-glacial origin, and appear to have been formed by the action of water derived from the melting ice upon the materials brought down as a direct result of ice action.

Glacial sands are generally brownish in colour, though this is not always an indication of a large percentage of iron. In many cases it is due to the presence of a peaty matter which tends to reduce the proportion of iron (see *Carbonaceous Sands*, p. 90). The glacial sands between St. Helens and Ormskirk (Lancashire) are of this character, the proportion of iron, according to Boswell, being only about 0·05 per cent, although they are dark brown in colour. The percentage of silica in these sands is 96-97 per cent.

Glacial sands are generally rather coarse and irregularly graded. Boswell found that the majority of the grains are between 0·25 and 0·5 mm. diameter, the deposits between St. Helens and Ormskirk containing about 12 per cent of particles smaller than 0·25 mm. diameter, whilst those of Scunthorpe, Lincolnshire, contain 7·6 per cent smaller. Some, however, are much finer, those in Durham containing 63·4 per cent of grains between 0·1 and 0·25 mm. and 32·9 per cent still smaller, whilst the sands at Liston, Suffolk, contain 47·8 per cent smaller than 0·1 mm. The grains are generally fairly angular, as little rolling or rounding action has accompanied their formation, the movement being more of a sliding nature which tends to produce angular grains, whilst the distance traversed is not sufficient to rub off the sharp corners. Glacial sands are much less regular than those formed wholly by running water. In some cases rounded grains do occur, but these are often derived from previously existing sedimentary rocks. In Cumberland and Lancashire deposits of this kind occur, the material having been derived from the Trias and other more ancient formations. Glacial sands usually occur in association with boulder clay. They often occur in lenticular masses in the clay, and consist of angular grains of quartz, together with variable (sometimes large) quantities of heavy minerals, including garnet, iron ores, tourmaline, hornblende, augite, hypersthene, zircon, rutile, kyanite, staurolite, and a small amount of andalusite.

Glacial sands are used for various purposes. Some of the purest glacial sands of Lancashire and of Ireland are used for the manufacture of glass bottles, and those of Ipswich for steel casting. The less pure and inferior sands are used for building and other purposes for which a pure sand is unnecessary. Those of Durham and Scunthorpe (Lincs) are used as moulding sands.

Glass Sands are those used in the manufacture of various kinds of glass and are usually very pure, containing at least 98·5 per cent of silica and little or no iron compounds.

Table XVIII., compiled by Boswell, shows the geological position of the principal glass-making sands in this country.

Table XVIII.—The Distribution of Glass Sands

Geological Position.	Name of Sand.	Locality.
Shore and Blown Sands.		
Glacial . . .	...	Crank, Rainford, etc. (Lancs).
Upper Eocene .	Headon Hill Sands	Alum Bay, Isle of Wight, etc.
	Barton Sands	Fordingbridge (Hants), Longdown, New Forest.
Lower Eocene .	Thanet Beds	Charlton (Kent), Rochester (Kent).
Lower Cretaceous	Lower Greensand	Aylesbury (Bucks), Aylesford (Kent), Godstone (Surrey), Hollingbourne and Bearsted (Kent), Leighton Buzzard (Beds), Lynn (Norfolk), Oxted (Surrey), Reigate (Surrey).
	Tunbridge Wells Sand	Ashurstwood (Sussex).
	Ashdown Sands	Fairlight and Bulverhyth (Sussex).
Middle Oolite .	Kellaways Beds	Burythorpe and South Cave (Yorks).
Lower Oolite .	Upper Estuarine Beds	Huttons Ambo (Yorks).
	Lower Estuarine Beds	Corby (Northants), Denford (Northants).
Upper Trias . .	Keuper Waterstones	Spital (Cheshire), Alderley Edge (Cheshire).
Lower Trias . .	Lower Bunter Sands	Worksop (Notts).
Carboniferous .	Coal Measures	Guiseley (Yorks).
	Carboniferous Limestone	Mold (Flintshire), Minera (Denbigh).
Lower Ordovician	Arenig	Stiperstones (Shropshire).
Doubtful Age (pre-Glacial)	Pocket Sands	Parsley Hay (Derbyshire), Brassington (Derbyshire), Low Moor (Derbyshire), Ribden (Staffs), Abergele (Denbighshire), Rhes-y-cae (Flintshire), etc.

The chief of the beds mentioned occur in the Lower Cretaceous formation, and comprise the Lower Greensand, Tunbridge Wells Sands, and Ashdown Sands. These beds are used for the best quality of glassware, the other formations in most cases being only suitable for inferior glass. For further information on glass sands see Vol. II. Chapter XII.

Glauconitic Sand is so called on account of the presence of the mineral glauconite, an amorphous, granular, or earthy hydrous potassic-ferric silicate of very variable composition, frequently containing also alumina, magnesia, and lime, found exclusively in deposits of marine origin, as in the Greensand beds of the

Cretaceous System. Pure glauconite is green in colour, but the sand-beds are not necessarily green, as iron and other impurities sometimes give them a brown colour which masks the green of the glauconite.

Glauconitic sands are sometimes used as fertilisers on account of the phosphatic matter they contain, and also for recovering potash, but otherwise they are of no special use.

Gold Placers are alluvial deposits of sand and gravel containing a large proportion of heavy minerals, including metallic gold. They are more widely distributed than any other valuable mineral placers, and are formed in two ways: (i.) by surface denudation, whereby the rock containing the metallic gold is disintegrated and the lighter material carried away, leaving a concentration of heavy minerals, either on the surface of the rock or at the bottom of some slope in the vicinity; (ii.) by fluviatile action, whereby much of the lighter materials have been removed and the heavier ones concentrated in river beds and lakes. The most important deposits are those of the second class, the gold being usually most abundant amongst the coarser gravels at the base of the deposits. In some cases natural riffles are produced by the upturned edges of rocks, and in the beds of clay or sand cemented by iron compounds which sometimes alternate with the gravel beds.

Gold usually occurs in association with heavy detrital minerals such as magnetite, ilmenite, haematite, chromite, garnet, zircon, spinel, etc., forming what are known as "*black sands*" (p. 82).

The gold consists of grains of various shapes, some being thin scales or flakes, whilst other grains are rounded or irregular. Their size varies from that of the finest dust to large nuggets or "pebbles."

Gold placers are chiefly found in the Recent and Pleistocene deposits of California, Alaska, Australia, and Siberia, but they also occur in many other geological formations, as on the Gold Coast, Africa, and also in the Transvaal — where gold occurs in ancient placers which have been consolidated and afterwards covered by other beds—in Russia (Ural Mountains and Siberia), and in Canada, particularly in British Columbia and Nova Scotia. Very small quantities of gold have been found in various localities, including Wales, and even sea-water retains a small proportion in solution.

The gold drift deposits of Australia consist of gravels, sands, and clays, placed quite irregularly and containing large boulders of quartz surrounded by gold-bearing sand and gravel.

In California the gold-beds lie at the base of the western flanks of the Sierras and consist of loose sand and gravel, covered by sheets of basalt and extending sometimes to a height of 2000 ft. above sea-level, with a thickness of 200 to 600 ft. The upper part of the beds consists of a reddish loam mixed with small gravel, below which is a coarse gravel with numerous boulders chiefly of quartz. The gold is scattered through the gravel, but is found chiefly in the lower part of the bed.

Gold-bearing beach sands are due to the movements of the

sea having concentrated the heavy particles and separated much of the lighter material. The gold in these deposits is usually associated with a black iron-sand, though in some places, as at Cape Yagtag (Alaska), garnets replace the iron-ore. Beach placers also occur in New Zealand, Oregon, and Chile.

The sand is of no serious value when the gold has been removed, and prior to its removal the value of the sand is solely dependent on the cost of extracting the precious metal. It is obvious that if 1 oz. of gold costs £4 to recover in a pure state whilst the market price for the metal is below this figure, the sand under consideration is of no value as a gold-bearing material.

Green Sands are chiefly due to the presence of the mineral glauconite as a film or coating on the grains of quartz and other minerals present. It may also be due to the presence of an exceptionally large proportion of certain hydrous magnesian silicates such as chlorite, talc, or serpentine. Hornblende, olivine, etc., may also give a greenish tinge to sand, though usually they are so easily decomposable that they are removed from the sands by various natural influences.

Greensand is the name applied to the marine beds lying below the chalk of the Cretaceous System. It takes its name from the green grains of the glauconite (p. 180) which it contains, but the name is somewhat misleading, as the general colour of these sands is brown. The occurrence and distribution of these beds have been described on p. 61. The Lower Greensands are of great commercial importance and include the Folkestone, Aylesbury, Leighton Buzzard, and Sandringham sands.

The *Folkestone Beds*, which are the highest in the Lower Greensand, consist of white or cream-coloured sands containing about 99 per cent of silica. The purest beds occur at Godstone in Surrey, where some of the sand is almost pure white, though in places it is contaminated by iron stains. According to Boswell, the best qualities contain about 99·56 per cent of silica and 0·06 per cent of iron oxide. The iron-content is rather high at Godstone, compared with parts of the bed in other localities, but the Godstone sand is more uniform and even-grained. At Reigate the proportion of silica is rather lower, but the percentage of iron is only 0·02. This is due to the fact that the iron compounds are concentrated into patches, thus leaving the rest of the material with a smaller proportion of ferruginous matter. A small quantity of calcareous matter is also present in the Reigate sand. At Westerham (Surrey) the beds are rather impure and of inferior quality. At Hollingbourne, Bearsted, and Aylesford in Kent the iron-content of the best portions of the beds is about 0·04 per cent, the general colour being from nearly white to cream, the latter predominating. Both the Reigate and Aylesford sands contain a small quantity of calcareous matter. At Rogate (Sussex) calcareous matter occurs in patches in the sand.

The principal mineral impurities in the Folkestone beds are

common to most Greensand beds and are principally tourmaline, kyanite, staurolite, ilmenite, zircon, rutile, and limonite. Muscovite mica also occurs to some extent. The proportion of heavy detrital minerals is generally quite low. At Hollingbourne and Bearsted, Boswell found less than 0·03 per cent of such minerals present in the sand.

The texture of the Folkestone beds is generally fairly uniform and fine. According to Boswell, at Hollingbourne and Bearsted about 94·6 per cent of the grains are between 0·25 and 0·5 mm. diameter. At Aylesford, Reigate, and Godstone a rather larger proportion of finer grains occurs, about 14·5 per cent of grains between 0·1 and 0·25 mm. diameter being present in Reigate sand, 16 per cent in that at Aylesford, and nearly 26 per cent in that at Godstone. At Oxted and Limpsfield the beds are rather coarse, there being about 12 per cent of grains over 0·5 mm. diameter and little more than 1 per cent under 0·25 mm. diameter.

The amount of fine "clay" present in the beds varies in different localities. In most cases Boswell found less than 0·5 per cent, but at Reigate about 2 per cent is present.

The Folkestone beds are used for various purposes according to their purity. The best qualities are used for glass-making. The Reigate sand is used principally for sheet glass and laboratory glass-ware. Common glass has been made from the deposits at Hollingbourne and Bearsted, but at present they are not used.

The poorer qualities of sand, which contain a higher proportion of iron, are used for building purposes, abrasive soaps, and as silver sand.

The *Aylesbury Sand* is one of the whitest and purest sands in this country; it occurs in beds about 18 ft. thick, in association with iron and carbonaceous matter, these materials splitting the white sand into beds 4-6 ft. thick. Aylesbury sand is very similar to those of Fontainebleau (France) and contains, according to Boswell, 99·8 per cent of silica and only 0·03 per cent of iron oxide. The usual mineral impurities of the Greensand formation are present in small quantities. It is very uniform in texture, over 78 per cent of the grains being between 0·25 and 0·5 mm. diameter, whilst about 15 per cent are between 0·1 and 0·25 mm. diameter, and about 6 per cent between 0·01 and 0·1. A typical microphotograph of Aylesbury sand is shown in Fig. 4. It is chiefly used in the manufacture of flint glass.

The *Leighton Buzzard Sands* vary from nearly pure white to pale yellow sands associated with carbonaceous matter to highly ferruginous deposits. The best beds of "pale sand" contain, according to Boswell, about 99·6 per cent of silica and 0·2 per cent of iron oxide. The impurities present are practically the same as in other Lower Greensands.

The texture of the Leighton Buzzard sand is somewhat coarse; Boswell found that 20-50 per cent of the material consists of grains between 0·5 and 1 mm. diameter, and 17-86 per cent

between 0·25 and 0·5 mm. diameter. There is practically no "clay" present. It is a very pure sand from a mechanical standpoint, there being sometimes only 0·1 per cent of material which is not true sand.

The best qualities of the Leighton Buzzard sand are used for glass-making. The coarser sands are principally used for filtering purposes, the manufacture of concrete, and for grinding, whilst the parts which contain too much iron to be used for other purposes are suitable for building. Some of the sand is used for casting in foundries.

Lynn or Sandringham Sand is found in the Lower Greensand beds to the east of the Wash in Norfolk (p. 64). It occurs in the Sandringham sands formation, and is worked at various places around King's Lynn, including Middleton and Gayton. The sand varies in colour from grey to reddish, the purest beds containing, according to Boswell, about 99 per cent of silica and 0·04 per cent of iron oxide, and are thus rather richer in iron than the Aylesbury sands. Lynn sand is also rather coarser, most of the grains being between 0·25 and 0·5 mm. diameter.

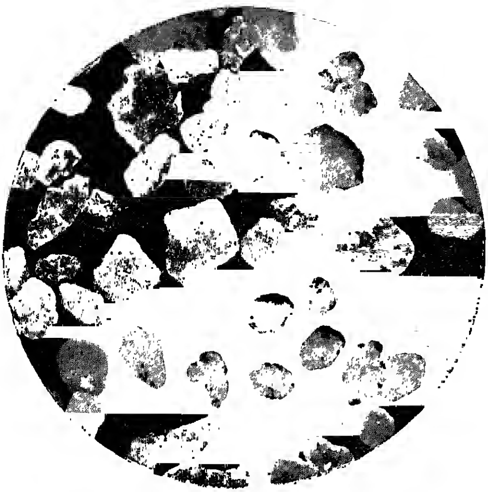

FIG. 4.—Aylesbury high silica sand. × 20.

The texture of Lynn sand is very remarkable. According to Boswell, it is the most even-grained glass-sand in the country, especially that found in the vicinity of Middleton, which contains about 95·1 per cent of grains between 0·25 and 0·5 mm. diameter. It is rather richer in iron than may be desirable, but is highly valued. The heavy detrital minerals present are characteristic of the Greensand formation generally, though Boswell states that the deposit is rather richer in felspar than most of the Greensands and that garnet occurs to a small extent.

The Lynn sand is very uniform in quality. It is used for various purposes, including foundry moulding, building, glass-making, etc. The purest beds are used for glass; some of the red sand which occurs extensively in these beds is used in the manufacture of black bottles, whilst the pale sands are used for window-glass, plate-glass, laboratory ware, electric lamp bulbs, bottles, etc.

Near Gayton the sands are more felspathic and contain only about 97 per cent of silica. The proportion of iron compounds is also considerably higher, being almost 0·19 per cent, and rather less true sand is present. Glauconite is disseminated through the sand usually as a coating over the silica grains, but in places it is concentrated into greenish seams. The Gayton sand is largely used for the manufacture of glass bottles and also for the hearths of Siemens open-hearth furnaces.

Grey Sands are of no particular value, but if their grey tint is due solely to carbonaceous matter and the sands are otherwise pure they may be used for glass-making, foundry-work, etc. A grey sand should always be tested for calcium carbonate prior to making an extensive examination, as limestone dust is of little value except in coal mines.

Hastings Sands comprise the beds between the Purbeck strata at the top of Oolite formation and the Wealden beds. They include the Tunbridge Wells sand, Ashdown sand, and Fairlight clay, and occur in the north-east of Sussex and the south-west of Kent. Their occurrence and distribution have already been described (p. 61).

The *Tunbridge Wells Sand* occurs at the top of the Hastings beds immediately below the Weald clay in the neighbourhood of Tunbridge Wells (p. 61). It consists of a creamy-white sand containing, according to Boswell, about 99 per cent of silica and 0·01 per cent of iron oxide, the colour deepening slightly on burning. About 85 per cent of the grains are between 0·1 and 0·25 mm. diameter, and there is rather a higher proportion of dust than in the Ashdown sand, which occurs in the same formation, the proportion of grains less than 0·01 mm. being 2·5-3·0 per cent. It also contains a rather larger percentage of heavy minerals (about 0·24 per cent), the principal ones found by Boswell being zircon, rutile, ilmenite, and tourmaline. Muscovite flakes, glauconite, and anatase also occur in small quantities. In places, the sand is hardened, forming a soft sandstone as at Ashurstwood, near East Grinstead.

The Tunbridge Wells sand is used for glass manufacture.

Ashdown Sands form one portion of the Hastings beds and occur chiefly around Fairlight and Hastings in association with liguite (p. 61). The sand is pure white and contains less than 0·02 per cent of iron compounds, this very low figure being due in all probability to the reducing action of the carbonaceous matter usually associated with the sand, whereby the ferrous salts are largely removed in solution by percolating waters. Boswell gives the following chemical analysis of the sand near Hastings :

Silica	99·47 per cent
Alumina	0·24 ,,
Ferric oxide	0·002 ,,
Lime	0·29 ,,
Magnesia	trace
Loss on ignition	0·20 per cent

This sample is almost as pure as the best Fontainebleau sand; on burning, it has a slightly pink colour. It is very even-grained and consists for the most part of grains between 0·25 and 0·5 mm. diameter, there being only 16 per cent smaller than 0·25 mm. According to the mechanical analysis by Boswell, there is about 99·8 per cent of true sand (*i.e.* grains between 0·1 and 0·5 mm.) in the deposit. This consists chiefly of fine quartz grains together with a very small proportion of heavy minerals (about 0·01 per cent), including magnetite, limonite, ilmenite, chiefly altered to leucoxene, brown tourmaline, zircon, rutile, and muscovite.

At Bulverhythe the sand is very similar to that previously described, but is rather richer in iron compounds. Boswell found that the grain-size of the bulk of the deposit is approximately the same, but there is a greater proportion of both the finest and coarsest grains, the total percentage of particles between 0·1 and 0·5 mm. being about 99 per cent.

Ashdown sand is largely used for glass manufacture, some parts of the beds being equal in quality to the best French glass-sands.

Infusorial Earth is a sand consisting of the siliceous remains of diatoms and other living creatures. (See *Diatomaceous Earth*, p. 96).

Iron Sands are black and brown sands which are rich in iron compounds. Black iron sands containing the magnetic iron oxide occur on the shores of the river Natashkwan, which flows into the Gulf of St. Lawrence about 530 miles north-east of Quebec. The sand occurs in patches in the dunes and sandy beaches on a long peninsula between the river and the sea, to the north-east of its mouth, and continuing for a distance of six to eight miles eastwards along the coast. The iron-bearing material has been concentrated by the action of the river's normal current, the incoming tide, the outgoing tide, and the winds blowing either up or down stream. The crude sand contains about 14·7 per cent of iron oxide and 4·43 per cent of titanic acid. The deposits have not been worked to any great extent, but an investigation was made upon them in 1913 by the Canada Department of Mines, Ottawa. Ferruginous sands occur in the beds known as *Northampton Sands* (p. 59) and are in some cases used as a source of iron-ore.

Other iron sands have not been fully investigated, but unless they are as rich in iron oxide as a good iron-ore they are of no value as a source of that metal. Usually, they can only be used for building and agricultural purposes.

The presence of iron sands in other purer sands is a serious detriment to the latter and one of the chief reasons why so many sands are of no serious commercial value. A typical iron sand is shown in Fig. 5.

Jurassic Sands, see *Oolite Sands* (p. 132) and *Lias Sands* (p. 124).

Kellaways Sands occur below the Oxford Clay of the Oolitic formation. Their occurrence and distribution have already been described on p. 58. They vary in colour from nearly white to

brownish, a pale brown being the predominant tint. The proportion of iron oxide varies in different localities. At Burythorpe, near Malton, Yorks, up to 0·22 per cent together with about 1·6 per cent of alumina and some quantity of calcareous matter was reported by Boswell, who also found that the mineral impurities present in the Kellaways beds are typical of the Inferior Oolite rocks, and consist chiefly of magnetite, ilmenite, garnet, rutile, zircon, staurolite, tourmaline, and muscovite. Towards Sancton the amount of mica present is considerably increased.

The Kellaways beds vary in texture in different localities, though that at Burythorpe is quite uniform and rather fine. At Burythorpe and Levening, Boswell found that approximately equal proportions of grains lie between 0·1 and 0·25 mm. and 0·25-0·5 mm. diameter respectively. At South Cave, however, over 90 per cent of the grains lie between the sizes 0·1 and 0·25 mm. diameter. The proportion of "clay" present is generally less than 1 per cent.

The sand at Burythorpe has been used in the past for glass-making, but it is not at present being worked. At South Cave the Kellaways beds are mixed with those from the Estuarine Series and used as moulding sand.

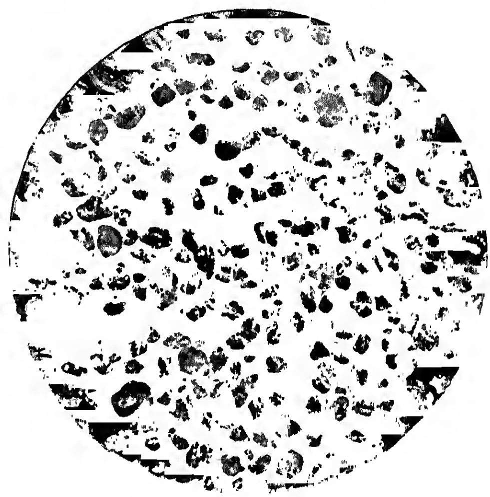

FIG. 5.—Magnetic iron sand. × 20.

Keuper Sands occur above the Bunter Beds in the Triassic System and consist largely of marine and aeolian material. Their occurrence and distribution have already been described on p. 52. Most of the sand-bearing material in the Keuper Series consists of soft greyish or white sandstones, the principal beds being the Keuper Water-stones, which occur chiefly in Cheshire (p. 53). Near Spital the sandstone is cream-coloured and yields a sand containing (according to Boswell) about 94·6 per cent of silica, 3 per cent of alumina, and about 0·06 per cent of iron oxide. The high proportion of alumina is due to felspar and clay, and is characteristic of the Keuper beds. The alumina renders the sand specially suitable for the manufacture of bottle-glass on account of the strength which it imparts to the ware. Other heavy detrital minerals occur up to about 0·06 per cent and include ilmenite,

magnetite, tourmaline, zircon, rutile, and anatase. The bulk of the grains are between 0·25 and 0·5 mm. diameter. The proportion of "clay" separated mechanically is generally less than 3 per cent, whilst the total amount of true sand is about 96 per cent.

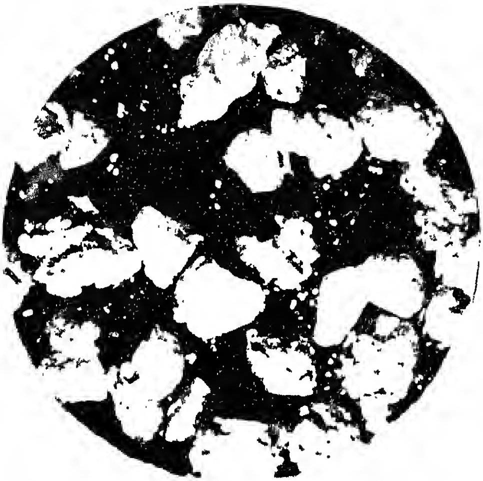

FIG. 6.—Alderley red moulding sand. × 20.

At Alderley Edge in Cheshire there are large tips of sand from the Keuper Waterstones which, according to Boswell, consist chiefly of grains between 0·25 and 0·5 mm. diameter, together with about 17 per cent of grains between 0·1 and 0·25 mm. The iron content is fairly low (about 0·12 per cent), but the percentage of alumina is fairly high. A typical microphotograph of Alderley Red moulding sand is shown in Fig. 6.

Kieselguhr, see *Diatomaceous Earth* (p. 96).

Lacustrine Sands are of the same general character as Estuarine sands, except that the organic constituents are different. Such sands are largely a product of fluviatile action, though in some cases, as in mountainous regions, much glacial material has found its way into the beds of lakes. Examples of this type of deposit are very common in Switzerland, especially in the Lake of Geneva, but they are not so readily recognisable in British sands. Lacustrine sands are usually fairly uniform in texture, but tend to be very variable in chemical composition, and when that is the case they are of little value. The purer varieties are used for glass, foundry work, etc.; the others make good building sands if the grains are not unduly rounded.

Lias Sands occur in the Lias formation (p. 56). They are seldom of great commercial value, but in some localities are largely used for building purposes.

Limy Sands are those containing limestone or other compounds of lime. They are partially fusible, as the lime and silica combine, when heated, to form a fusible silicate, but if such sands are heated they do not melt completely. On the contrary, an apparently unaltered mass remains on heating the sand to the highest temperatures in a gas-heated furnace, but if the heated mass is allowed to cool it falls to pieces at a touch, producing a mass of fused and

unfused grains. Limy sands are best avoided for all industrial purposes; their composition is usually variable and their behaviour is always uncertain. Their chief use is in agriculture, where they lighten the soil and at the same time neutralise any acidity in it.

Lithomarge is very similar to but less ferruginous than *Bole* (p. 84). It may be regarded as a ferruginous sand compacted with clay to form a soft stone. It is sometimes used as a source of iron, but is of little commercial value as a sand.

Loam is a term used to describe a light open soil consisting of sand, clay, and carbonaceous matter. Other terms such as "sandy loam," "clayey loam," "calcareous loam," are used to denote the predominating constituent.

Broadly speaking, any sandy clay may be termed a loam, but when less than 20 per cent of clay is present the term "sandy loam" is preferable. Sandy loams are of great value in iron foundries for casting purposes. Loams containing less sand are often of value for brick-making, as some clays are too plastic and would shrink excessively if used alone. With sand, however, the shrinkage is reduced and good bricks can be made. Highly sandy clays are used in the manufacture of "cutter" and "rubber" bricks (see Vol. II. Chapter I.). Some loams contain a large proportion of gravel, and this is costly to separate.

The term "loam" must not be confused with one meaning of the German word "*lehm*," which signifies a product of the action of the weather on glacial drift and other rocks, forming a kind of loess (see below).

The disintegration of Triassic rocks gives rise to a light sand or a somewhat stiff loam, whilst the Lias of Oxfordshire also forms a rich friable loam. Any rocks which yield a mixture of clay and sand on exposure may be regarded as potential sources of loam.

Artificial loams are often made in order to produce a material of definite composition and properties. They are made by grinding clay and sand in a suitable mill.

Loess is a fine silty material sometimes erroneously termed "clay," but it neither puddles nor holds water like clay. It occurs in large deposits extending over large areas in America, Europe, and Asia.

Loess is found up to a height of 5000 ft. in the Carpathians, 8000 ft. in Shansi (China), and probably higher farther west. In North China, according to Richthofen, it is 1500-2000 ft. thick. The adobe of North America—a similar material—is sometimes 2000-3000 ft. thick.

Loess consists of angular quartzose sand of a dirty yellow, brownish, grey, or black colour mixed with 10-30 per cent of silt and clayey matter, and, in some cases, with chalk, limestone, and carbonaceous material.

Felspar, hornblende, and heavy minerals common to sands occur in variable and often considerable proportions, and mica

flakes are disseminated quite irregularly through the mass. The particles are chiefly angular in shape, and are intermediate in size between fine sand and clay. Its most distinctive characteristic is its behaviour when weathered, for, whilst sand and clay are worn down to gentle slopes, the loess stands in vertical faces which often present a roughly columnar appearance. Shovel marks and wheel tracks remain clearly defined for years.

The origin of these deposits is much disputed. It is probable that three different forces have taken part in the formation and that it is due to a combination of glacial, fluviatile, and aeolian actions. A loess-like material found in America and termed "adobe" (p. 79) appears to be of fluviatile origin, though it may partly be of aeolian origin. The extraordinary uniformity of loess suggests that it is an aeolian deposit, especially as it usually occupies the high ground, whereas water-deposits are usually in valleys or hollows (lake-beds). A dry climate is essential to its formation.

The loess occurring in the plains of China consists of a fine, soft, crumbling, calcareous silt of a yellowish or buff colour, formed probably by the accumulation of wind-borne dust produced as a result of the drying of pre-existing glacial mud. It is very homogeneous, sometimes stands up in walls several hundred feet high, and is curiously resistant to weathering actions. It is probably held together to some extent by the many fine vertical tubes in it, formed by rootlets and lined with a calcium carbonate film.

In Europe much of the loess consists largely of clay, the deposits on the Rhine containing only 18 per cent of sand and 16 per cent of chalk, the remainder being clay. Its composition, however, varies considerably.

The occurrence of true loess in Great Britain has been denied; in any case it can only occur in insignificant quantities.

In Russia the loess (locally known as "tchernozom") is of a similar nature to that of China, but, on account of the large proportion of organic matter, it is black. It is thought that the European deposits are chiefly the result of glacial action.

Loess appears to be useless as an industrial material, and even agriculturally it is of variable value.

Manganese Sands and Gravels are sometimes produced by the weathering and surface denudation of manganese ores, especially in Japan (see also *Wad*, p. 167). They sometimes form a source of manganese, but are not otherwise of great value.

Marine Sand is the sand formed on the seashore, but the term is also applied to all sands originally deposited from sea-water. It is quite incorrect to suppose that all marine sands are salt, though those still in contact with sea-water are so. Marine sands are usually coarse, very variable in composition and in size of grain. Those derived from ancient sea-beaches are often consolidated into sandstone and have to be crushed before use. Whilst

sands from existing seashores are of doubtful value—except for some building purposes of a rough character—those derived from marine deposits of remote geological periods are often valuable on account of their uniformity, alike of grain, size, and composition. The Greensands, Bagshot sands, Thanet beds, and some of the Bunter and Keuper deposits are of marine origin.

Metalliferous Sands and Gravels are deposits containing a large proportion of particles of metallic minerals which have been concentrated by the action of water, which has removed the grains of lower specific gravity. This concentration of heavy minerals in sands is due to several causes :

(i.) The normal current of a river tends to carry sand slowly along the bed towards the mouth of the river.

(ii.) The incoming tide reverses the flow of water in the mouth of the river and causes the latter to deposit its suspended load, and also carries a considerable quantity of sand up the river.

(iii.) Winds, either up or down stream, lift the dry sand from the surface of the beaches at low water. As the top layers of sand become dry, the lighter particles are blown away from the heavier sand. The heavy sand is also moved by the wind, but at a much slower rate. In this manner the heaviest grains are gradually concentrated, and in the course of hundreds of years large beds of heavy sands are produced.

(iv.) The outgoing tide added to the flow of the river causes the sands to rush towards and out of the river's mouth.

By these various means the sand is first carried down the river to the sea and is then driven up on the beaches by the tides and prevailing winds, after which the constant wash of the water carries the lighter particles ahead of the heavier ones, leaving the latter in thin bands and layers parallel to the shore. Successive waves add fresh material and continually separate the lighter from the heavier minerals. The wind then continues the separation as described above.

In some cases deposits of heavy detrital minerals may be produced by the decomposition *in situ* of metalliferous veins and rocks, followed by the removal of the lighter minerals by various denuding agencies, leaving the heavy minerals behind as a highly concentrated deposit of the particular mineral which predominates.

The principal metals found in concentrated surface deposits are iron, gold, titanium, tin, tungsten, platinum, palladium, iridium, manganese, cobalt, zirconium, thorium, etc. For further information on these deposits see *Placers*, p. 133.

Miocene Sands.—It is very doubtful whether any such sands occur in this country (see p. 72).

Moler is a sandy material somewhat resembling kieselguhr or diatomaceous earth (p. 96), but it is less refractory and contains a considerable proportion of clay and volcanic ash, for which reason it is self-binding and can be made into bricks without any

other bond. It is found chiefly in Norway, and a typical analysis of this material as used by Moler Products, Ltd., is as follows :

Silica (chiefly diatoms)	66·9
Ferric oxide	6·9
Alumina	13·0
Lime	1·0
Magnesia	1·6
Sulphuric anhydride	0·2
Alkalies	0·8
Loss on ignition	9·6
	100·0

It is chiefly used for the manufacture of insulating bricks, but these are more fusible than the ones made of purer kieselguhr.

Monazite Sand is a sand containing a large proportion of the mineral monazite, which has recently become important as a source of thoria and ceria. It is chiefly found in sands along the sea-shore at Travancore, India, and is derived from the gneisses. The selective action by the waves on these sands (p. 127) has led to the local concentration of the monazite in large quantities. Near Cape Comorin at low tide the beach is often a glistening mass of rounded grains of yellow monazite. Monazite also occurs in association with the graphite of South Travancore and in pegmatites. In the graphite mine at Vellanad, sixteen miles north-east of Trivandrum, monazite was found in a rock filling a fault crack. This rock is composed mainly of brownish crystals of monazite in a matrix of felspar with a little quartz.

Monazite also occurs widely in the Tinevilly district in the older dunes, in the dry beds of the streams draining eastwards from the hills, and in the beach sands, where they have undergone slight concentration. It occurs in the streaks of black sand at Waltair and Bimlipatam, in similar streaks near the entrance to Chilka Lake in Orissa, and sparingly in concentrates from Idar Central.

Large placers of monazite sand occur in South America, especially in Brazil, in the provinces of Bahia, Minas Geraes, Espirito Santo, Matto Grosso, and Goyaz. The Brazilian deposits are the most important, much of the sand containing 90 per cent of monazite and 4-7 per cent of thoria. In the United States monazite is found in many localities. Thus in Idaho and Montana it occurs as an accessory mineral in granite and in the sands and gravels derived from pre-existing igneous rocks. Placer deposits, river and beach sands containing monazite, occur in various parts of Indiana, South Dakota, Nevada, Utah, Washington, Wyoming, Colorado, Oregon, California, and New Mexico. The principal areas are in the South Mountain region of North Carolina, particularly near Mars Hill, Madison County, and in the adjoining parts of South Carolina and in the alluvial deposits along the streams from the great granite area around Centerville, Idaho.

In Idaho monazite occurs in sands derived from the disintegration of a light grey granite. In the Musselshell district the sands contain 31-55 per cent of monazite and 0·88-1·85 per cent of thoria.

Monazite sand occurs in various parts of Nigeria, in the Federated Malay States, and in the protected states of Kedah and Kelantan.

Monazite sands are usually black, due to the presence of large proportions of magnetite and ilmenite; they are red when garnets are in excess, but where there is abundance of quartz or calcite a grey sand is produced. The portions richest in monazite have a yellowish tinge.

The monazite in the sands or crushed rock is concentrated by washing in sluices in a similar manner to alluvial gold. The concentrated sand is then dried, and the magnetite and other ferruginous materials extracted electro-magnetically, the product containing 65-70 per cent monazite, 5-7 per cent of thoria, together with valuable proportions of zircon, garnet, rutile, corundum, etc.

Monazite is essentially cerium orthophosphate, but it always contains other rare earths, including thorium, lanthanum, and yttrium.

Table XIX., due to S. Johnstone,[1] shows the composition of various samples of monazite:

TABLE XIX.—ANALYSES OF MONAZITE

	Espirito Santo, Brazil.	Alcobaca, Brazil.	North Carolina.	Ratnapura, Ceylon.	Travancore.	Ekole, Nigeria.	Ebara, Nigeria.	Pelang, Malay.	Kulium, Kedah.
Thorium oxide	6·06	6·5	6·49	10·29	10·22	5·00	5·50	8·38	3·53
Cerium oxide, Lanthanum oxide, etc.	62·12	61·40	31·38 30·88	27·37 30·13	31·90 28·00	30·72 30·02	31·40 29·20	25·46 32·72	64·05
Yttrium oxide	0·80	0·70	..	2·14	0·46	2·74	2·00	2·80	2·4
Ferric oxide	0·97	1·5	..	0·81	1·50	3·0	0·75	0·81	0·64
Alumina	0·10	0·08	..	0·17	0·17	0·35	0·05	2·78	0·07
Lime	0·21	0·30	..	0·11	0·20	0·15	0·10	0·61	0·17
Silica	0·75	0·61	1·4	1·03	0·90	1·20	0·82	0·92	1·08
Phosphoric acid	28·50	28·16	29·28	27·67	26·82	26·29	29·02	23·92	27·87
Loss	0·38	0·61	0·20	0·20	0·16	0·25	0·11	1·28	0·52

Monazite is generally found in small grains or monoclinic crystals of a yellowish to brownish colour somewhat resembling amber. Occasionally it is found in well-developed crystals one-fourth to three-eighths of an inch in length, and more rarely in crystals 2 in. or more in length. The more perfect crystals are very small, seldom exceeding 5 mm. in length; many are 0·1-0·2 mm., and more frequently the crystals are microscopic in dimension. Some monazites contain very little thoria, whilst others contain a large proportion up to 32 per cent; yttrium and erbium oxides, uranium oxide, zirconia, manganese oxide, and titanium oxide may also be present. A typical monazite sand is shown in Fig. 7.

[1] *J. Soc. Chem. Ind.*, 1914, 33, 55.

Monazite has a resinous to vitreous lustre, and is translucent to sub-transparent. It is brittle, with a conchoidal to uneven fracture and a hardness of 5 on Mohs' scale; it can readily be scratched by felspar (hardness 6) or quartz (hardness 7); it has a high specific gravity (4·6-5·3).

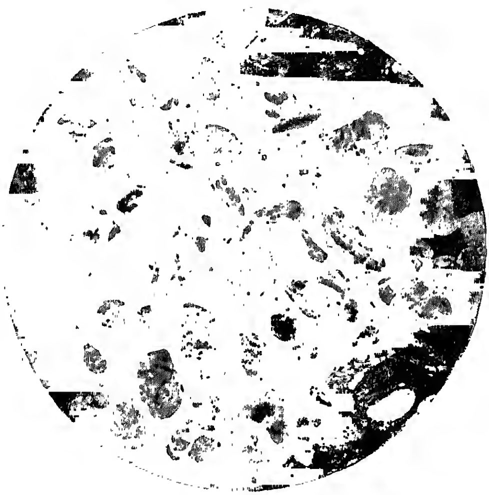

FIG. 7.—Monazite sand. × 20.

Monazite is chiefly used as a source of thoria and ceria for the manufacture of incandescent mantles.[1] Monazite is also used as a source of cerium, lanthanum, and other rare metals which when alloyed with iron possess the property of emitting a flame of great brilliancy with little heat and smoke when scratched with steel. As the sparks produced readily ignite gases, tinder, alcohol-wicks, and explosives, these alloys are used commercially as substitutes for matches, etc., and in military signalling.

Moulding Sand is that used for casting metal articles in foundries and other works. Particulars of the requirements and use of moulding sand will be found in Vol. II., Chapter VI.

Table XX., due to Boswell, shows the geological position of the most important moulding sands in this country.

Mud is a fine-textured fragmental material formed in water, usually by fluviatile action, and corresponds to the dust deposits formed on dry land, the only difference being that the former are wet and the latter dry. Muds are usually derived from fine fragmental material carried out into lakes or seas by river-action, sea-erosion, etc. They consist of minute particles of quartz, felspar, mica, and other minerals, together with a variable proportion of clay, organic matter, and calcium carbonate. Various minerals are sometimes present in sufficient quantity to give the muds a characteristic colour, such as the black and the blue muds of the Black Sea, which contain iron sulphide and bisulphide, precipitated from solution as a result of anaerobic bacterial action.

[1] A. von Welsbach patented the use of thoria for mantles in 1886; it was found later that the presence of 1 per cent ceria gave a greater illuminating effect.

TABLE XX.—DISTRIBUTION OF MOULDING SANDS

Geological Position.	Locality.
Recent	Thames sand.
Glacial	Durham.
Doubtful age (pre-Glacial)	Abergele (Denbighshire); Barrow-in-Furness, Brassington (Derbyshire); Parsley Hay (Derbyshire); Ribden (Staffs), etc.
Pliocene	St. Agnes, St. Erth, Cornwall.
Eocene	Bagshot beds of Southampton and Thanet beds of Kent.
Cretaceous . . .	Upper Greensand at Haldon, Deven. Lower Greensand at Leighten Buzzard and Oxford.
Jurassic	Kellaways beds at South Cave, Yorks; Uppor Estuarine beds at Huttons Ambo, Yorkshire.
Trias	Keuper Waterstones at Spital, Cheshire; Bunter Sands at Armthorpe, Bawtry, Burghwallis, Doncaster; Heck, Hensall, Snaith and Whitley [illegible] Lenton, Mans- [illegible] on and Worksop [illegible] Lancs; Run- [illegible] Warwickshire; Wolverhampton in Staffs; Compton, Kidderminster, Stourbridge, Stourport, and Wombourne in Worcestershire; and Belfast in Ireland.
Permian	Lower yellow sands at Castleford and Pontefract, Yorks.
Carboniferous . .	Wolsingham in Durham; Haydon Bridge in Northumberland; Auchenheath, Drumcavil, Garngad, Garnkirk, and Glenboig in Lanarkshire; Kilwinning and Monkreddon in Ayrshire; Bonnybridge in Stirling; and Cookstown, Co. Tyrone.

The proportion of mica is usually higher in muds than in sandy rocks, since flakes of mica remain longer in suspension than the more compact grains of quartz, and are therefore carried farther from the shore. Felspar is also fairly common, and minute crystals of zircon and other rarer minerals also occur.

Muds may also be regarded as extremely fine sands contaminated with clay.

Oil Sands are those containing petroleum or other volatile hydrocarbon oils which can be recovered by distillation. Extensive deposits occur along the banks of the River Athabasca around Fort McMurray in Alberta, Canada, and elsewhere. These deposits are analogous to the much better-known oil-shales in which the oil-forming matter is similarly associated with indurated clay.

Oilstone Sand—made by crushing "oilstone"—is used for grinding the brass fittings of mathematical and optical instruments. The oilstone from which it is made is a fine-grained hone-stone obtained from the interior of Asia Minor, containing 70-75 per cent of silica, 20-25 per cent of calcium carbonate, and a little alumina.

A similar material is found in Charley Forest; at Whittle Hill; Charnwood Forest, Leicestershire; near Llyn Idwal in North Wales; and near Tavistock, Devonshire. Several varieties of oilstone are also obtained in the United States.

Oldhaven and Blackheath Sands are merely of geological importance. They have no commercial value (p. 70).

Oligocene Sands include various deposits of partially marine and partially lacustrine origin, including the sands of the Hamstead, Osborne, Bembridge, and Headon Hill beds of Hampshire and the Isle of Wight (p. 72). These sands are usually somewhat calcareous and of little commercial value, but in some localities they are fairly pure.

The Headon Hill sands of the Isle of Wight are nearly pure white, and contain ferruginous particles together with associated beds of lignite. According to Boswell, these sands contain about 97 per cent of silica, 1·9 per cent of alumina, and about 0·11 per cent of iron oxide, the impurities consisting chiefly of rutile, tourmaline, and staurolite, and other characteristic detrital minerals of the Bagshot formation. The sands are fairly uniform in texture, about 84 per cent being between 0·1 and 0·25 mm. diameter and nearly 4 per cent over 0·25 mm. diameter. There is also a notable proportion of "clay," usually amounting to about 2·5 per cent. The sand has been used for glass-making, but it is not at present worked.

Oolite Sands, see *Kellaways Sands* (p. 122) and *Estuarine Sands* (p. 102).

Parting Sand is sand used in metal-casting to separate different parts of a mould; thus, it is sprinkled on to the joints of the mould to prevent the sections from adhering to each other. The sand used for this purpose is generally of an inferior quality, the only essential feature being the absence of bond (see also Vol. II. Chapter VI.).

Phosphate Sands consist chiefly of tri-calcium phosphate, and have been produced by the action of phosphoric acid of organic origin upon calcium carbonate. They are chiefly used as artificial manures. They occur in Belgium, in France on the river Somme, in the United States, and elsewhere. In some cases, they are extremely fine in texture, much of the material passing readily through a 200-mesh sieve. Tri-calcium phosphate is only slightly soluble in water, and must be converted into a more soluble form, such as superphosphate, before it can be used as a manure.

Pit Sand is a general name given to sands which are dug or quarried, as distinct from those which are dredged or obtained by other means. The term has little or nothing to do with the origin or mode of formation of the sand, and is only useful as showing how the sand has been obtained. It has one advantage, however, in that a sand which is dredged from a river, lake, or sea is almost certain to consist chiefly of round-grained particles, whereas a pit sand may (though not necessarily) consist of sharp

grains. In some cases the term pit sand is used to indicate a sharp-grained sand, though all pit sands are not "sharp."

Placers are alluvial deposits of sand and gravel containing a large proportion of heavy detrital minerals, such as gold, platinum, tin ore, emeralds, rubies, sapphires, diamonds, etc. These alluvial deposits may be quite recent or very old; they may occur in the bank or bed of a stream or lake as an ancient or existing beach, or they may form terraces varying in age from Pleistocene to Recent times. They may occur on or near the surface, or as *deep leads*, *i.e.* covered by recent beds of gravel, lava, or other volcanic rocks. In some places they occur as consolidated gravels or conglomerates, interbedded with other rocks (see also under the names of the various metals and under *Gem Sands and Gravels*, p. 112).

Plastering Sand is mixed with lime to form a fine mortar or plaster used for finishing interior walls or ceilings. The chemical composition is not of such great importance as the sharpness of the grains, though a white or silver sand is preferable to a darker-coloured one (see also Vol. II. Chapter IV.).

Platinum Placers are sand and gravel deposits containing platinum in association with iridium, rhodium, palladium, ruthenium, and osmium, as well as heavy minerals such as chromite, magnetite, ilmenite, and gold. The crude platinum occurs as water-worn fragments, nuggets being comparatively rare; it occurs in many river and alluvial sands derived from igneous rocks, but usually in such minute quantities that it cannot be recovered at a profit.

About 90 per cent of the world's supply of platinum is obtained from Russia, on the slopes of the Ural Mountains, around Nischne Tagilsk and Mount Solovief, where the metal is derived from intrusive peridotites which have been disintegrated and the heavy minerals concentrated. In California, British Columbia, Brazil, Columbia, and Borneo, platinum is found in association with gold placers. Other deposits containing platinum occur at Fifield in New South Wales, in California and Oregon, in the United States, and in Alaska. Recently the sands of some of the rivers of Tasmania have been worked for platinum and iridium.

The Russian deposits contain about 30-35 grms. per ton of a metal containing up to 76 per cent of pure platinum, 4 per cent of iridium, 2·3 per cent of osmium, 3·5 per cent of ruthenium, and 1·4 per cent of palladium, with less than 0·5 per cent of gold.

Platinum is recovered from alluvial deposits by hand-sluicing or dredging. The methods used are often very crude, so that only about one-third of the total metal present is obtained.

Pleistocene Sands, see *Glacial Sands* (p. 115).

Pliocene Sands.—The occurrence and distribution of Pliocene sands have been described on p. 73. They are usually of a yellowish or reddish colour, the red sands at St. Erth in Cornwall containing, according to Boswell, about 86 per cent of silica, 5·29 per cent of alumina, and 2·74 per cent of iron oxides. The Belgian yellow sand has a similar composition. The iron oxide forms a thin

film over the surface of the grains of quartz. The sands of Cornwall are a little more fusible than those of Belgium on account of the larger proportion of alkalies present. Heavy minerals, according to Boswell, are abundant, and consist chiefly of tourmaline, staurolite, andalusite, kyanite, rutile, topaz, zircon, ilmenite, magnetite, and limonite. Mica is also present. The texture of these sands has been studied by Boswell, who found that the Cornish sands consist chiefly of grains between 0·1 and 0·5 mm. diameter, though a considerable proportion of clay is sometimes present. The coarsest sands contain over 85 per cent of grains larger than 0·25 mm., whilst the finer sands may contain less than 40 per cent above this size. The Belgian sands are usually equivalent to coarse Cornwall sands.

The proportion of clay is low in the Belgian and coarse Cornish sands, but Boswell has found that some of the fine Cornish sands contain nearly 14 per cent of clay.

Pliocene sands are chiefly used for casting metals.

Pocket Sands are deposits produced by the disintegration of the Mountain Limestone rocks of Derbyshire, North Staffordshire, and more rarely in North Wales and Ireland. They form pockets or "swallow holes" in the limestone, often of a deep cup-shape. The pockets vary considerably in size, some being merely small pipes, whilst others have an area of between 100 and 200 square yards, the form of the deposits being largely determined by the jointing of the limestone. Many of the deposits are of great depth; near Friden the sands have been found to persist at a depth of over 200 ft. without showing any signs of this being the bottom of the deposit. The occurrence and distribution of pocket sands has already been fully described on p. 42.

The sands vary from white to brown or red through various shades of grey, cream, and yellow. The pure white sands are quite low in iron. They consist chiefly of rounded grains, and are, therefore, of aqueous origin, though some angular grains also occur. Some of the sand has probably been carried to its present position by streams of water acting on the shales, sandstone, and grits on the higher ground, but the bulk of the deposits is most probably a residue left when the calcareous portion of the Carboniferous Limestone rocks was removed by solution. The residue collected into pockets and became mixed with débris from the overlying Millstone Grit.

According to Boswell, the heavy detrital impurities present in the sands consist chiefly of anatase, apatite, cassiterite, epidote, rutile, spinel, staurolite, and zircon. Limonite occurs in the deposits at Abergele, and leucoxene and brookite are found at Oakmoor. The purest of these sands usually contain very little felspar and mica, but those of inferior quality are richer in these minerals, some being quite micaceous. A certain amount of clay also occurs associated with the sand. The purest deposits found by Boswell are at Abergele in Wales, where over 99 per cent of silica is present,

with only 0·54 per cent of alumina and 0·04 per cent of iron oxide. Some of the Parsley Hay sand contains only 0·05 per cent of iron oxide, but it is accompanied by over 18 per cent of alumina. The Brassington sands contain nearly 7 per cent of alumina and about 0·18 per cent of iron oxide. The high percentage of alumina in the Derbyshire deposits is due to the presence of a larger proportion of clay associated with the sand, some part of the deposits containing sufficient clay to render the material plastic when wet.

The texture of pocket sands is very variable on account of the mode of formation, though in some parts it is fairly uniform, as at Abergele, where Boswell found about 78 per cent of the grains are between 0·25 and 0·5 mm. diameter, and 8-9 per cent of grains are between 0·5 and 0·1 mm. diameter. He found no material of the " clay " grade present, and nearly 98 per cent of the material may be classed as true sand. At Rhes-y-cae, in Flintshire, about 85 per cent of true sand is present.

The Derbyshire deposits are less uniform in texture, the best being at Brassington and Carsington, where, according to Boswell, 60-70 per cent of the grains are between 0·25 and 0·5 mm. diameter, with about 2 per cent over 0·5 mm. diameter and under 15 per cent between the sizes of 0·1 and 0·25 mm. In other parts of Derbyshire, larger proportions of the finer grains occur, the sands at High Peak containing only about 21 per cent of grains over 0·25 mm. diameter. The proportion of " clay " present is considerably higher in Derbyshire than in Wales. The sands at Newhaven, Longcliffe, and Brassington usually contain less than 10 per cent of " clay," but at Carsington over 18 per cent is present, and at High Peak over 26 per cent. The Staffordshire deposits at Ribden are also very rich in material of the " clay " grade, in one bed over 50 per cent being present. These sands contain from 29-72 per cent of true sand.

At Park Mine, near Askham-in-Furness (Lancs), pockets of sand occur in haematite in the Carboniferous Limestone. The pockets of haematite are oval in shape, and decrease rapidly in width as the depth increases. They vary in size, some of the larger pockets being about 480 ft. deep and 900 ft. in diameter. They contain an outer layer of haematite, inside which is a layer of reddish clay from 6 in. to 6 ft. in thickness, the central part of the pocket being filled with loose sand and fragments of a pale grey friable sandstone of different sizes. Ferruginous, micaceous, loamy, and clayey materials also occur in the sandstone. The amount of sand present varies in different pockets, the proportion increasing near the Red Sandstone area and decreasing towards the Silurian beds.

The purest white pocket sands are generally employed for the hearths of open-hearth furnaces, and have also been suggested for glass-making. The grey sands (often termed *Ganister sands*), which contain more clay, are used as ground ganister, and are mixed with crushed silica rock, or sometimes with the quartzite

pebbles found in the same deposits, and made into silica or semi-silica bricks. The yellow sands have been used for steel-casting.

Pozzuolana is similar to trass, and consists of volcanic lavas which have been influenced by superheated steam and carbon dioxide in such a way that they have been reduced to a fine state of division. Pozzuolana also resembles clay which has been heated to redness, but its composition is very variable. It is amorphous, though in some cases crystals of various igneous rocks occur in it.

It derives its name from the town of Pozzuoli, near Naples, where it was first obtained by the Greeks and later by the Romans. Pozzuolana also occurs in the Auvergne Mountains, the Mountains du Vivarais, and in the Gulf of Lyons in France, at Teneriffe in the Canary Isles, and in the Azores.

The analyses in Table XXI. show the composition of some types of pozzuolana.

TABLE XXI.—ANALYSES OF POZZUOLANA

	Silica.	Alumina.	Ferric Oxide.	Lime.	Magnesia.	Potash and Soda.	Water.
Rome (Stanger and Blount)	58·58	22·74		4·06	1·37	..	..
Naples (Stanger and Blount)	63·18	19·8		5·68	0·35	..	..
Vesuvius (Thorpe)	44·0	10·5	29·5	10·0	tr.	1·0	2·5
Vesuvius (Thorpe)	46·0	16·5	15·5	10·0	3·0	4·0	5·0
Auvergne Mts. (Thorpe)	47·9	34·2		8·2	3·9	2·6	3·2
Azores Isles (Chateau)	54·7	20·5	6·3	2·2	1·7	2·2	12·4

Pozzuolana, trass, etc., possess the property of forming a hydraulic cement when they are mixed with lime and are made into a paste with water, no heat being required as in the manufacture of Portland cement. This is due to the combination of the material with the water forming complex substances which harden on drying to form a strong mass. Pozzuolanas may be divided into (*a*) the direct products of volcanic action, such as true pozzuolana *santorin* (p. 155), *tosca* (p. 165), *tetin*, and *trass* (p. 165) ; (*b*) the decomposition products of igneous rocks termed *arênes* (p. 80) ; (*c*) artificial pozzuolanas.

Artificial pozzuolana consists of burned clay, or blast-furnace slag. These materials, when ground, possess properties similar to natural pozzuolana, though to a much smaller extent, lightly burned clay being much superior to slag in this respect.

Pozzuolana is largely used in the preparation of cements, mortars, and concrete.

Primary Sands are those which are formed by the direct disintegration of igneous rocks, such as granite. They may contain grains of very diverse sizes, but where atmospheric agencies have

acted on them the sands are classified to some extent and are more uniform in grain size. Most commercial sands are of a secondary nature (see also p. 7).

Pumice Sand is not exactly a sand, but may be conveniently classed as such, as in many ways it does resemble other sands and is used for many purposes for which they are employed. Pumice consists of a volcanic glass which has been ejected in a spongy, viscous state from active volcanoes, and was afterwards subjected to a sudden cooling, which was too rapid to allow the glass to crystallise. It is very light and spongy, on account of its having contained a considerable amount of dissolved gases which were suddenly released on the solidification of the viscous mass. The vesicles are rounded or elongated, due to the flowing of the lava, and the structure is composed of thin partitions or threads on which the abrasive value of the material depends.

Pumice occurs in many parts of the world in the vicinity of active and extinct volcanoes, but that used in this country is chiefly obtained from the Lipari Islands, north of Sicily. An inferior grade, *alessandrina*, is used for smoothing oilcloth. A little is imported from Teneriffe. Pure white pumice dust occurs over wide areas in Nebraska, Kansas, California, Idaho, Utah, South Dakota, Wyoming, Oregon, Colorado, Oklahoma, and Iowa, the chief sources being in Harlan and Lincoln counties in Nebraska.

Table XXII. gives typical analyses of two of the most important varieties of pumice.

TABLE XXII.—ANALYSES OF PUMICE[1]

	Silica.	Alumina.	Ferric Oxide Ferrous Oxide.	Lime.	Magnesia.	Potash.	Soda.	Loss.
Cape di Costagna, Lepari Isles .	73·70	16·27	2·31	0·65	0·29	0·73	4·25	1·80
Orleans, Nebraska	69·12	17·64		0·86	0·24	6·40	1·69	4·05

The specific gravity of pumice is less than that of water, on account of its porous character, but the specific gravity of the powdered material is 2·3-2·4.

Pumice sand is produced by screening the natural material and so separating the larger pieces, or by grinding the material to powder.

Pumice is used principally as an abrasive. Lumps of the inferior qualities are used for smoothing oilcloth, whilst the sand or powder is used in the manufacture of metal polishes and abrasive soaps. It has also been employed for polishing stones, glass, and ivory, and in a finely powdered state (called *pounce*) for preparing parchment. Insulating bricks and fireproof ware of low specific

[1] Thorpe's *Dictionary*.

gravity have also been made from pumice sand, as well as cements and cheap glass-ware.

The presence of hard felspar crystals is detrimental to the value of pumice for polishing, as they cause scratches.

Quartzites are rocks consisting of a mosaic of quartz crystals without any regular outlines, these grains being united by a cement of almost pure silica which has been recrystallised or deposited in a colloidal state around the original crystals. In some quartzites the outlines of the original grains can be readily distinguished, but in others this is very difficult. When the cementation has been sufficiently prolonged, the cemented grains fit so closely that they interfere and prevent the production of crystal faces. Fig. 8 shows a typical quartzite viewed by means of polarised light. Pure quartzites are white, but others are coloured owing to the impurities present in the cement, or in the quartz of which they are composed. Iron is the principal colouring agent, giving the rocks a brownish tint. The grey colour of Carboniferous quartzites is due to the presence of finely divided carbonaceous matter. Chlorite and other impurities may also impart their characteristic colours to the quartzite.

FIG. 8.—Quartzite. × 25. (Crossed nicols.)

The principal varieties of quartzite are: (1) *Vein quartz*, which is produced as a result of hydrothermal action, and forms coarse interlocking crystals with little or no cement; (2) *Conglomeratic quartzite*, in which quartzite pebbles are cemented together by siliceous material; (3) *Quartz schist*, a metamorphosed silica rock which, when examined microscopically between crossed nicols, shows bands and waves of colour due to distortion by pressure; and (4) *Amorphous quartzites*.

The principal impurity found in quartzites is iron oxide, the greater proportion being in the ferric state, though in some quartzites chalybite (ferrous carbonate) occurs. Various alumino-silicates may also be present, chiefly in the form of felspar, mica, kaolinite, or clay. Mica frequently occurs in foliated quartzites along the lines of foliation. Both potash and soda-lime felspars occur, and lime may also be present in the form of calcite, dolomite,

or calcium phosphate. A small quantity of hydrous sodium silicate sometimes occurs in association with the secondary silica cement, introduced probably by an alkaline solution, some of which was retained by the silica in the form of silicate of soda.

Magnesia may occur as dolomite, or as ferro-magnesian silicate such as serpentine, this latter being very infrequent. Titanium occurs to a limited extent as rutile, brookite, or anatase, the first and third occurring in characteristic needle-like crystals, whilst brookite occurs in large flakes surrounded by minute secondary crystals in the cementing silica. Where the proportion of titanium is high it is generally present in this form, having probably been deposited from solution simultaneously with the cementing silica. Zircon occurs in minute crystals, generally in negligible proportions.

It is important to remember that a small percentage of alumina and certain other elements may represent a much larger proportion of impurity. Thus, 10 per cent of felspar would show only 1·6 per cent of potash and 1·8 per cent of alumina, the remaining 6·6 per cent being silica, which is included in the total silica. Hence, a material appearing to contain only 3·4 per cent of impurities may actually contain 10 per cent.

The principal quartzites in this country occur in the Metamorphic, Pre-Cambrian, Cambrian, Ordovician, and Carbonaceous rocks, whilst a very important source of quartzite on the Continent (Germany) is known as amorphous quartzite.

Metamorphic quartzites have been used only to a small extent as sources of sand. Their texture varies considerably. At Kentallen they are quite coarse, the grains being up to 1·0 mm. diameter, whilst on the Isle of Jura and Islay they average about 0·2 mm. diameter. The proportion of iron is generally very low. Felspar and mica occur in varying proportions, veins of these minerals sometimes occurring along the joints, as at Glen Orchy. As a rule, the proportion of impurities is very low, the cement in most cases being completely siliceous. Many apparently excellent deposits of these rocks have not been worked as yet; those which have been worked have been used chiefly for abrasive purposes. The rock from the Kentallen district is used for polishing and for soaps. The beds at Glen Orchy have been suggested as suitable for the manufacture of silica bricks, whilst the disintegrated quartzites on the beaches of Jura have been suggested for refractory purposes and glass manufacture.

Pre-Cambrian quartzites are used to some extent as sources of sand. Their occurrence and distribution have been described on p. 39.

The Anglesey quartzites are pale grey in colour and fairly fine-grained, the grains varying in size, according to Boswell, from 0·05 - 4 mm. in diameter. The Holyhead quartzites are more uniform in texture, the grains averaging 0·2-0·3 mm. diameter. Felspar is almost absent, and only a small proportion of mica occurs, generally in the form of sericite. Iron oxide sometimes occurs in

the joints of the rock, causing stains. According to Boswell, the rock has the following composition :

Silica	99·32	per cent
Alumina	0·19	,,
Titanium oxide	0·03	,,
Ferric oxide	0·02	,,
Lime	0·12	,,
Magnesia	0·08	,,
Potash	..	
Soda	..	
Loss on ignition	0·21	,,
	99·97	

The rock is generally very hard, but at Holyhead the quartzite is sheared in places and is termed " soft rock " ; it is readily ground up and used for ganister. The hard, massive quartzite is used for the manufacture of silica bricks. Silver or silica sand is also prepared for use in steel-casting, whilst the fine dust from the crushers is collected and sold as " silica flour," for painting steel ingot moulds and castings, and also for polishing-powders and scouring-soap.

The vein quartz at Slieve More, Achill Island, contains about 99 per cent of silica and 0·04 per cent of iron oxide. Boswell found that the principal impurities, which amount to about 0·1 per cent, are metallic iron, green mica, and haematite. The crushed rock varies considerably in texture, some samples containing over 85 per cent of grains between 0·25 and 0·5 mm. diameter, whilst others contain over 50 per cent of grains larger than 0·5 mm. diameter and 40 per cent or more between 0·25 and 0·5 mm. diameter. Some portions are extremely fine, and contain from 43-99 per cent of material finer than 0·01 mm. diameter, so that they belong to the " clay " grade. The total amount of true sand present in the best qualities is about 98 per cent, whilst in other parts of the deposit the proportion of true sand may vary from practically *nil* to 63 per cent. The sand is chiefly used in the manufacture of soaps.

The " sand " at Muckish Mountain, Co. Donegal (Ireland), is derived from the disintegration of a Pre-Cambrian quartzite of the Dalradian formation. The rock is found in all stages of decomposition. In some parts it consists of a crumbly sandstone which is easily crushed between the fingers ; a large quantity of sand is also present, though the main portion of the deposit consists of soft rock containing, according to Boswell, about 99·5 per cent of silica and about 0·02 per cent of iron oxide. In some parts of the bed the amount of iron oxide is very small (0·009 per cent), whilst in others it rises to nearly 0·03 per cent. There are very few impurities present, zircon being practically the only heavy mineral impurity.

The texture varies considerably in different parts of the bed,

but Boswell found an average of about 70-74 per cent of grains between 0·25 and 0·5 mm. diameter, and up to 22 per cent either over 0·5 mm. diameter or less than 0·25 mm. diameter. Up to 2·5 per cent of grains over 1 mm. diameter may occur. The proportion of "clay" present is generally very small, and seldom exceeds 1·5 per cent. The proportion of true sand varies from 95-99 per cent. This material has been suggested as suitable for glass-making, much of the deposit being suitable for the best optical glass.

Cambrian quartzites are largely used as sources of sand in South Staffordshire and Warwickshire. Their occurrence and distribution have been described on p. 40. The two principal Cambrian quartzites are the Lickey quartzite and the Hartshill quartzite.

The *Lickey quartzite* consists of a very pale grey rock, stained in places by iron. The cement is siliceous, and clay, felspar, and mica occur in the rock, the sericitic form of mica being fairly common. Some cherty matter is also present. The material is used chiefly as road-stone and for the manufacture of silica bricks. Some is also crushed and used as ground ganister. It has also been suggested as suitable for the hearths of the open-hearth furnaces.

The *Hartshill quartzite* consists of a hard grey rock with a pinkish tinge, consisting, according to H. S. Bell, of 94·45 per cent of silica, 2·55 per cent of alumina, 0·77 per cent of alkalies, and 0·86 per cent of iron oxide. In some parts of the beds the proportion of felspar is rather high. The cement is chiefly siliceous, but some clay also occurs. The grains are somewhat irregular in size, but average about 0·3 mm. diameter. The rock has only been used as a road-stone, but some parts may be suitable for the manufacture of silica bricks.

Ordovician quartzites are chiefly found in Shropshire, under the name of Stiperstone quartzites. Their occurrence and distribution have been described on p. 40. They are of a greyish colour with sometimes a greenish tinge, and associated with carbonaceous streaks which penetrate the rock irregularly. This quartzite contains, according to Boswell, about 96 per cent of silica, 2·24 per cent of alumina, and 0·06 per cent of iron oxide. It is of rather irregular texture, the size of the grains varying from about 0·2 mm. at Nill's Hill to 0·3 or 0·4 mm. at Granham's Moor. It is cemented chiefly by a siliceous cement, though in places it is somewhat argillaceous. The proportion of felspar and mica varies, but is lowest at Granham's Moor. The grains are fairly angular in most parts, though some are sub-angular. The rock is chiefly used in the manufacture of refractory bricks, and for road-stone. Silica flour is also produced by grinding it to a fine powder. It has also been suggested by Boswell that the Stiperstone quartzites might be useful for the manufacture of glass.

Carboniferous quartzites.—True quartzites generally occur in the Ordovician and older formations, but some of the beds of the Millstone Grit in Wales approach very closely to true quartzites.

They occur chiefly in the Basal Grit of the Millstone Grit Series of South Wales, though some parts of the Cefn-y-fedw sandstone of North Wales (p. 46) might also be classed as a quartzite.

The Millstone Grit rocks of South Wales consist very largely of quartzites, much of the rock having been hardened by the intense silicification. In some places, however, the quartz cement is absent, and the material forms either a soft, loose sandstone or an incoherent sand or gravel. The best qualities of rock consist of a fine-grained, bluish-white quartzite containing practically no felspathic matter.

At Hirwaun the rock is pale grey in colour, and consists of grains about 0·2 mm. diameter, associated with grains of chert, quartzite, etc., and a little plagioclase felspar. The loose rock and sand are of a similar nature.

At Penwyllt, Neath, the rock consists of particles up to 0·4 mm. diameter, and there is also a rock known locally as "spar," which contains pebbles up to $\frac{3}{4}$-in. in diameter.

At Bynea, Llanelly, the rock is extremely fine-grained, the particles being chiefly between 0·03 and 0·05 mm. diameter; whilst at Mynydd-y-Gareg a moderate proportion of micaceous matter occurs in the interstices between the grains of quartz. In other parts of the Kidwelly district the rock is somewhat coarser, containing particles up to 0·3 mm. diameter and some felspathic matter.

The Brynamman beds consist chiefly of white or pale grey sand, composed of grains between 0·1 and 0·15 mm. diameter. Some of the beds are composed of a pale grey or pinkish sandstone, cemented by siliceous matter and clay, and containing some felspar, whilst an adjacent very fine-grained bed consists of particles about 0·05 mm. diameter.

The Upper Cwmtwrch rock is very pure, being very pale grey, and containing no felspar or mica and only a little interstitial impurity. The softer beds are somewhat coarse, and consist chiefly of grains 0·4 to 0·5 mm. diameter and containing some clay.

A very fine bed locally termed "blue stone" is somewhat micaceous. The silica rock at Llandybie is very similar to the Cwmtwrch rock, only a very small proportion of felspar and mica being present.

In Glamorganshire, the Basal Grit is very similar to the corresponding beds of Carmarthenshire. The famous Dinas rock of the Vale of Neath is a very pure quartzite containing only about 0·5 per cent each of lime and iron oxide, and about 2 per cent of alumina. It is yellow or grey with a pale bluish tinge, is semi-transparent at the edges when carefully observed, and possesses many of the characteristics of crystalline silica (quartz). It consists chiefly of grains about 0·2 mm. diameter, and is associated with chert, clay, and some mica, derived from the decomposition of felspar. The Dinas material occurs both as rock and as sand with thin veins of clay, each form being of equal value for silica bricks and apparently consisting of the same material.

In Pembrokeshire the quartzite is moderately fine-grained, and of a greyish colour spotted with iron compounds. Heavy detrital minerals are especially abundant.

The South Wales quartzites are used largely for the manufacture of silica bricks, ganister mixtures, steel-moulders' composition, paint, etc. The sand is used for the same purposes, for lining open-hearth furnaces, and for silica cement.

Amorphous quartzites are sometimes used in Germany as sources of sand for the manufacture of silica bricks. They do not occur in this country, but in Germany they are represented by *Findlings quartzites* or *Erratic Block quartzites*, which consist of fresh-water deposits of Tertiary origin belonging to the period during which lignite was formed. Under the microscope the grains of quartz are seen to be very small, with rounded edges, and are distributed uniformly through an amorphous mass of what Wernicke terms "basal cement." Hence the term "amorphous quartzites." Their origin is quite different from that of other quartzites, as they appear to have been formed of minute grains of sand cemented together by a siliceous jelly which gradually hardened and formed a siliceous cement. The chief accessory minerals in these quartzites are zircon and tourmaline. Rutile and muscovite, which are found in almost all other quartzites, are not found in these erratic quartzites. They have some resemblance to ganister, but the grains of silica in the latter are larger. When crushed, the rock breaks into very minute crystals, so that the expense of fine grinding is rendered unnecessary. They also have the advantage that, when heated, they attain their maximum expansion after very few hours, and in this way are in marked contrast to other quartzites. On repeated heatings they do not expand appreciably, hence their great value as a refractory material.

They are chiefly used for the manufacture of silica bricks for electric and other metallurgical furnaces, where the requirements are very stringent.

Although the name Findlings quartzite implies that this material is found in small isolated masses, it also occurs in massive form; the latter is the one most largely used for silica bricks.

Quicksand is a sand consisting of highly rounded grains produced by the long-continued action of water. It is readily distinguished by its very small rounded grains. If piled it continually runs down, thus making a very flat pile. Owing to the roundness of the particles it cannot be cut when in a pile as can angular sand. This type of sand is useful for hour-glasses and other apparatus where a highly rounded sand is required, but it is useless for building and similar purposes.

Recent Sands are those which have been produced within comparatively recent times, and include fluviatile, estuarine, and deltaic deposits generally, as well as deposits produced by aeolian, volcanic, and organic and chemical actions (see also p. 76).

Red Sands usually owe their colour to the presence of haematite,

which gives various tints from a deep blood-red to a pale flesh colour. The brown colour due to limonite is usually associated to some extent with the red colour of the haematite, thus giving a modified red tending towards brown. The red colour of Triassic, Permian, Devonian, and other rocks, and the purple colour of some sandstones, are due to the presence of ferric oxide, and the dull brown or yellow colour to ferric hydroxide.

The blotching and variegation of colour in sand-beds is due partly to irregular distribution of the iron compounds, and partly to the differences in their hydration and reduction by organic matter, and the removal of iron from some parts of the beds by carbonated water.

Many sands are pale in colour in the natural state, yet become red when calcined (see *Red-burning Sands*, below).

Red-burning Sands are so named from their colour after they have been heated to a fairly high temperature; this colour is due to the presence of iron compounds, which, on heating, are decomposed and oxidised, forming red ferric oxide, which gives the characteristic colour to the material. The colour is not entirely dependent on the proportion of iron present, but on the presence of lime (which reduces the colour by forming a white compound), the size of the grains of the iron-bearing mineral, and the extent to which it is disseminated through the sand. Thus, if the iron occurs in relatively large particles more or less concentrated in some parts of the sand, it may not colour the sand to a very great extent; but if it consists of very fine grains, evenly disseminated through the material, the colour may be much more pronounced, even though a smaller total proportion of iron is present.

Red-burning sands are generally less refractory than paler ones, and consequently can only be used where resistance to heat is not so important. They are of no use where the colour of the sand is especially important, or where it might spoil the product, as in glass manufacture, and are consequently used for inferior purposes. The very red sands are only suitable for building purposes, concrete-making, etc., but the better qualities may be employed for facing bricks and tiles, dark glass-ware, foundry casting, steel-casting, etc. (see also *Red Sands*, p. 143).

Refractory Sands is a general term, including all sands which can be used in furnace or other situations where a high temperature is attained. There is no generally recognised standard of heat resistance in this country, but, by many users, materials are not considered refractory unless they will withstand heating steadily to a temperature of 1580° C. (Cone 26) in an oxidising atmosphere, without showing any signs of fusion. This test is only of limited value, because in actual practice other influences must be taken into consideration, such as the action of the furnace-gases, the influence of slags and of sudden changes in temperature; a sand is therefore not usually considered to be refractory unless it will withstand the conditions obtaining in commercial furnaces. As

these are seldom defined in detail, only actual trial will show whether a sand is sufficiently refractory for use in any particular case.

In the broad sense, the word "refractory" is used to denote (i.) resistance to any temperature to which a material is likely to be exposed; (ii.) resistance to any pressure likely to be put on it by adjacent masonry, or by the contents of the furnace; (iii.) resistance to the cutting and abrasive action of flame, flue-dust, and any other materials with which it may come in contact, including accidental blows from a poker or clinkering iron; (iv.) resistance to such sudden changes in temperature as are unavoidable in ordinary furnace practice; and (v.) uniform expansion or contraction within reasonable limits.

Few refractory sands fulfil all these requirements under very severe conditions, and the user must, therefore, decide to what extent he will forego some of the (to him) less important requirements. To a very large extent this method of "compromise" depends on local circumstances for success, and without full details no satisfactory guidance can be given. It must also be remembered that the skilful use of the materials and the construction of the furnace also play an important part in the lasting qualities of the sand.

The chemical composition of the refractory sand must be adapted to the reactions which occur when it is used. Most natural, refractory sands are siliceous, and so can only be used where the reactions occurring in the furnace, or location where they are used, do not have any adverse effect on the material. Some other natural sands, such as zircon sands, etc., may be used in special cases. Various artificial sands, such as carborundum fire-sand (p. 86), may also be employed as refractory sands. Mixtures of sands may sometimes be employed in preference to single ones.

In selecting a refractory sand for any particular purpose, it must always be remembered that the substances with which the material comes into contact when heated will play an important part in the resistance it offers to heat. Thus, a siliceous (*acid*) sand will be destroyed rapidly if heated in contact with a base, such as lime. The two will react with each other to form a fresh compound which is much less heat-resisting than either the acid or the base taken separately. Similarly, a basic sand, such as zircon sand, will be attacked if brought into contact with an acid material at a high temperature, a fusible compound being formed which will rapidly destroy the furnace and the sand.

Hence, refractory sands may be divided into three classes:

(*a*) *Acid sands*, including all sands rich in silica and siliceous materials.

(*b*) *Neutral sands*, including carborundum fire-sand.

(*c*) *Basic sands*, such as zirconia sand, powdered magnesia, etc.

Acid sands, in order to be refractory, must consist almost wholly of pure silica. The presence of small quantities of other minerals,

such as felspar, mica, etc., which introduce small percentages of lime, magnesia, potash, soda, or iron into the mixture, seriously reduce the refractoriness, and so render the sand useless for high-temperature work. The proportion of heavy detrital minerals may be quite small, yet may seriously impair the value of the sand unless it is specially treated in order to remove these undesirable constituents. Lamellar spangles of mica are more deleterious to the refractoriness of sand than are irregular grains of felspar. Similarly, the presence of siliceous materials in a basic refractory sand is deleterious. Further particulars on the use and requirements of refractory sands will be found in Vol. II. Chapter VII.

Residual Sands are variously defined as: (*a*) those which have been left behind at the place where they were originally formed by the decomposition or disintegration of some rock; (*b*) those which have been left when a mixture of materials has been subjected to some denuding action, whereby part of the deposit has been removed and carried away, whilst the rest has remained behind; and sometimes as (*c*) those which have been collected by glacial agency.

Residual sands in group (*a*) include all primary sands (p. 136), as these have been formed in this manner. In group (*b*) are included deposits which have been left behind by the disintegration of sedimentary rocks, such as the pocket sands of Derbyshire, Staffordshire, and Wales (p. 134). Residual sands of the (*b*) type may sometimes consist of a concentrated mass of some material which was too heavy, or in some other way too difficult, to be carried away by the particular denuding action which was acting on the material. Section (*c*) sands are residual in the sense that they have been left behind when the ice which collected and transported them was melted.

On account of their mode of formation, residual sands may be either very pure or very impure. They are generally very variable in composition, as there has been little or no classifying action, so that they consist of an irregular conglomeration of coarse and fine particles of all the materials of which the original rock was composed, except those constituents which may be soluble and have previously been removed. The purest residual sands are those in section (*b*), in which, in a certain sense, most sands may be included.

Rottenstone is a soft, porous, friable rock resulting from the decomposition of impure siliceous limestones. By the percolation of water, containing carbon-dioxide in solution, through the rock, most or all of the lime is removed, leaving a siliceous skeleton and any other impurities which may not be soluble.

The sources of rottenstone have previously been described (p. 44).

The composition of the stone depends on the rock from which it was formed. The following analyses, due to Dr. Pollard, show

the composition of two varieties of Welsh rottenstone, A being of best quality, while B is inferior :

	A.	B.
Silica	80·82	70·87
Titanium oxide	0·29	0·55
Alumina	5·82	9·78
Ferric oxide	3·79	4·61
Lime	1·43	1·60
[illegible]	0·88	1·32
[illegible]	..	0·27
Phosphoric acid	1·36	1·39
Ferrous sulphate	..	..
Soda	0·3	0·56
Potash	1·40	2·43
Water and organic matter	4·09	6·80

The precise composition is, however, of less importance than the angularity and minuteness of the grains and the freedom from hard crystals of felspar, etc. At the same time, it should be noted that some of the best qualities of rottenstone in Wales contain minute grains of crystalline silica.

Rottenstone is chiefly used as an abrasive, the rock being washed and ground. It is used in the form of powders and polishes for polishing metals, marble, etc. Tripoli is sometimes erroneously termed rottenstone.

River Sands are described under *Fluviatile Sands* (p. 104).

Sand Scale is a deposit of calcium carbonate formed during the evaporation of brine in the manufacture of salt. It is not a true sand, and its name is misleading.

Sandstones (Fig. 9) consist chiefly of an aggregate of quartz grains, cemented by siliceous material formed either by sedimentation in rivers, lakes, or seas, or by the accumulation of wind-borne detritus, which is later consolidated by the entrance of some cementing medium. Sometimes other than siliceous material is present in the cement and gives the name to the sandstone, *e.g.* ferruginous or calcareous sandstones. In other cases the stone is named after the predominating mineral impurity, as micaceous and felspathic sandstones. Sandstones are generally somewhat friable (breaking with uneven fracture), porous, and liable to be stained by the intrusion of impurities in solution.

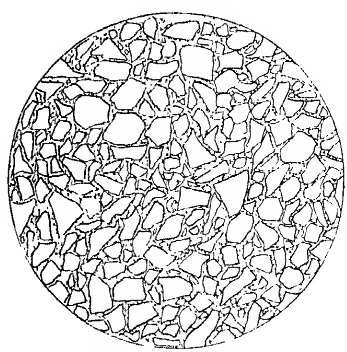

FIG. 9.—Micro-structure of sandstone.

The principal impurities in sandstones are felspar and mica, but other minerals may be present, such as chlorite, clayey matter, calcite, iron oxides, garnet, tourmaline, zircon, epidote, rutile,

anatase, etc. In Kentish rag, Spilsby sandstone, etc., calcite occurs in large crystalline masses.

The grey colour of sandstones is due to fragments of shale, etc., or to the presence of ferrous carbonate, finely divided iron pyrites, and, in exceptional cases, to iron phosphate.

Sandstones may be divided into several classes: (i.) Grits; (ii.) Sand rocks; (iii.) Freestone; and (iv.) Greywackes.

Grits are coarse-grained sandstones.

Sand rocks are loose, friable sandstones.

Freestone is a sandstone (though sometimes the term is also applied to limestone) which can be cut into blocks in any direction without a marked tendency to split in any one plane more than in another. It occurs in beds, but is not divided into laminae, as are most sandstones.

Greywackes are rocks consisting of a compact mass of rounded or subangular grains of quartz, felspar, slate, or other minerals or rocks, cemented by a siliceous, felspathic, calcareous, or other cement. Their colour varies from grey, through brown, to black, especially where much carbonaceous matter is present. Some greywackes are pale green or purple in colour. The texture varies from a coarse grit to a fine stone. It is sometimes very fine-grained, and is almost exactly like some igneous rocks; in fact, it is often composed mainly of granite débris, quartz-porphyry, or other felspathic rocks.

Many Palaeozoic and Lower Mesozoic sandstones are greywackes, and appear to have been formed by the accumulation of grains of igneous rocks, so much so that it is sometimes difficult to distinguish them from igneous rocks.

Gaize is a sandstone in which the matrix is free silica (soluble in a boiling solution of potash) which has been precipitated as impalpable white powder of low specific gravity. It is an important constituent of the Upper Greensand of England and France, sometimes up to 40-70 per cent being present, *e.g.* in the Farnham and Merstham firestones.

Sandstones which are suitable sources of sand for various purposes occur in most formations above the Devonian or Old Red Sandstone Series.

Carboniferous sandstones are largely used as sources of sand for the iron and steel industries and for the manufacture of refractory bricks. They occur irregularly in each of the great divisions of the Carboniferous rocks, their geological distribution being described on p. 42. Among the most important of these sandstones are the ganisters (p. 104), which are noted for their high resistance to heat.

In the Carboniferous Limestone Series in North Yorkshire are several commercially useful deposits of sandstones. At Wensley, Yorks (p. 44), a bed of white sandstone consisting of grains about 0·1 mm. diameter, cemented by siliceous matter with practically no impurities, lies below the pencil-ganister, and is worked for

silica bricks. The lower part of what is called the Nattrass Gill ganister at Gold Hill, Wearhead, is not a ganister at all, but a pale grey sandstone consisting of grains between 0·1 and 0·15 mm. diameter, cemented by a siliceous cement containing some material derived from decomposed felspar. In places it is somewhat iron-stained.

In Durham, the Brigg Hazel rock of Lanchead, Weardale, and Harperley (p. 44) consists of a fine-grained whitish or greyish sandstone with grains up to 0·2 mm. diameter, cemented by a small amount of siliceous matter with some quantity of heavy detrital minerals. A little chert and felspar occurs at Harperley, whilst mica occurs in the Lanehead rock. The dark grey or blue lower beds at Harperley are not so valuable, being generally rejected in favour of the better quality material. The Harperley rock is rather inferior as a refractory material to that at Lanehead; it is entirely used for the manufacture of silica bricks. The Lunedale rock is a hard, fine-grained sandstone with grains up to 0·2 mm. diameter, and containing some decomposed felspar and chert, as well as titanium minerals and ferruginous matter.

The Aid Crag silica rock of Northumberland is a buff-coloured, soft micaceous sandstone containing about 97 per cent of silica. The purest rocks are nearly white and are almost free from impurities, but most of the best contain mica and some clay, as well as ferruginous matter. They are generally fairly coarse-grained, the particles being generally about 0·3-0·4 mm. diameter. This rock is not much used as a source of sand, but blocks of it are used for furnace work.

The Carboniferous Limestone "sand" worked at Waen, near Mold (p. 44) in North Wales, consists of a soft, white sandstone. It is readily crushed, and is quite pure, containing, according to Boswell, about 99 per cent of silica and only about 0·024 per cent of iron oxide, so that it has practically no iron stains. It is very uniform in texture, the main portion of the material being of grains between 0·25 and 0·5 mm. diameter. There is also about 12 per cent of grains less than 0·25 mm. diameter and up to 10 per cent of grains over 0·5 mm. diameter. Much of the finest material can readily be removed by washing. There is very little heavy detrital material present in the material, that which does occur consisting chiefly of ilmenite partly converted into leucoxene, anatase, tourmaline, zircon, and rutile. Some decomposed felspar also occurs. This "sand" is principally used for the manufacture of soap, and has been suggested as suitable for glass-making and various refractory purposes, such as linings of open-hearth furnaces.

The sand at Minera (p. 47), which belongs to the same formation, is rather coarser and less uniform in texture. In a sample examined by Boswell about 17-18 per cent of grains were over 1 mm. diameter, and a total of nearly 50 per cent exceeded 0·5 mm., as distinct from less than 10 per cent in the case of the Mold

leposits. The colour of the sands in this district is whitish, turning grey on heating.

The sandstones occurring in the Carboniferous Limestone rocks of Scotland are generally white or pale grey in colour and fairly fine-grained. The proportion of interstitial matter varies considerably, and mica is also present in varying amounts. Ferruginous and carbonaceous matter is generally present in moderate proportions, and the beds may be locally iron-stained.

The Scottish Carboniferous Limestone series includes some of the "Rotten rocks"—so called on account of the decomposition of the felspar in them forming mica, silica, and kaolin. The alkalies have been partially removed, so that the rocks are fairly refractory. They also contain a notable proportion of hydrated iron oxide. They are usually fairly coarse; according to Boswell, the Auchenheath rock (p. 45) contains 25·7 per cent of grains over 1 mm. diameter and 69·1 per cent between 0·1 and 1 mm. diameter. They vary in colour from white to yellowish or pale brown.

At Caldwell (p. 45) sand is derived from a soft sandstone which has been partially decomposed and is, consequently, easily reduced to powder. The material varies from a cream to a reddish-brown colour, the percentage of iron oxide being, according to Boswell, 0·04. The silica is rather low, being only about 94 per cent, whilst alumina occurs to the extent of about 4 per cent. Nearly 0·1 per cent of heavy detrital minerals occur, the chief being garnet, tourmaline, limonite, ilmenite, zircon, rutile, and epidote. Muscovite mica flakes also occur. Boswell found that the texture of this material is fairly coarse, about 83 per cent of the grains being between 0·25 and 0·5 mm. diameter and up to 6 per cent over 0·5 mm. diameter, whilst up to 5 per cent of "clay" is present. The total amount of true sand in the unwashed material is about 94 per cent, whilst in the washed product over 99 per cent is present. This sand is chiefly used as a refractory material, though it has been worked for glass-making.

At Kilwinning (p. 45) a soft white sandstone containing nearly 99 per cent of silica and only 0·02-0·03 per cent of iron oxide occurs in a bed over 20 ft. in thickness. It is low in alumina, containing only about 0·5 per cent. Boswell found very little impurity present, the amount of heavy minerals being only about 0·02 per cent, and consisting chiefly of ilmenite, leucoxene, limonite, muscovite, tourmaline, sillimanite, rutile, and zircon. The natural material contains rather a large range of sizes of grain, a little over half occurring between 0·25 and 0·5 mm. diameter. About 30 per cent of the grains are between 0·5 and 1 mm. diameter, and up to 14 per cent are over 1·0 mm. diameter. After washing, the quality is improved considerably.

At Plean, near Stirling, the texture of the stone is more uniform; in a sample examined by Boswell, about 80 per cent of the material consisted of grains between 0·25 and 0·5 mm. diameter. The colour of this rock is slightly greyer than that at Kilwinning. The

Plean rock contains rather more " clay," up to 4·5 per cent being present.

Similar rocks occur at Cowie, near Stirling, Kingscavil, near Linlithgow, Glenboig, and Hailes, near Edinburgh (p. 45). They vary in colour from grey to a brownish colour, the proportion of iron in most cases being quite low.

The sandstones of the Calciferous Sandstone Series of Scotland consist chiefly of fine-grained and generally buff-coloured stone, consisting of particles of silica associated with micaceous and felspathic matter, and some carbonates with ferruginous matter as a cementing medium. Some of the Ayrshire beds are quite soft and easily broken down to a moderately sharp sand. These sandstones have not been largely used as sources of sand, but some beds have been tried for steel-moulding, whilst the Ayrshire beds have been suggested as suitable for lining open-hearth furnaces.

The Calciferous Sandstone rocks of Ireland yield several valuable sands. Thus, at Coolkeeragh, near Londonderry (p. 42), sand is obtained from soft white or pink sandstones belonging to this series, and containing about 85 per cent of silica and nearly 9 per cent of alumina, a considerable amount of partially decomposed felspar and clay being present. According to Boswell, about 0·18 per cent of iron compounds is present, up to 7 per cent of " clay," and about 0·05 per cent of heavy minerals, including muscovite, chlorite, tourmaline, garnet, zircon, rutile, leucoxene, anatase, and ilmenite. The texture is fairly uniform, and consists of about 76 per cent of grains between 0·25 and 0·5 mm. diameter, together with about 7 per cent each of grains over 0·5 mm. and between 0·1 and 0·25 mm. diameter. This material is used chiefly for the manufacture of glass bottles.

The white sand from Cookstown, Co. Tyrone, derived from a soft white sandstone, occurring in the same series, contains, according to Boswell, about 97 per cent of silica, 1·6 per cent of alumina, and about 0·04 per cent of iron compounds. In some of the washed samples of the best sand, the proportion of iron is reduced to 0·02 per cent. Only about 0·03 per cent of heavy minerals are present, these consisting chiefly of zircon, rutile, anatase, ilmenite, and tourmaline. Felspar and clay occur to the extent of about 3·5 per cent. The texture of the material is fairly uniform, about 80 per cent of the grains being between 0·25 and 0·5 mm. diameter, whilst up to 10 per cent of the grains may be larger than 0·5 mm., and up to 5 per cent smaller than 0·25 mm. diameter, apart from the " clay " present. This sand is used for the manufacture of glass bottles.

The *Millstone Grit* rocks consist almost entirely of sandstones ; only parts of the beds are commercially useful as sources of sand, though much of the rock is quite suitable for building-stone.

Some of the sandstones of Durham which cannot be classed either as ganister or as bastard ganister, and yet are used for some of the same purposes as ganister, consist chiefly of pale grey or

coloured rocks, usually somewhat micaceous, having a fairly texture, the grains averaging about 0·1 mm. or less in diameter. erally the cement is for the most part siliceous, the impurities present in it usually occurring in larger proportions than in the true ganisters. At Knitsley Fell, in the silica rock occurring above the pencil ganister the grains of silica are coated with iron oxide, and quite a large proportion of impurities are present in the cement.

At Castle Hill Quarry, Consett (p. 48), some of the sandstone is cemented chiefly by ferruginous matter. The sandstones in this district are chiefly used for the manufacture of silica bricks, sometimes with the addition of ganister or bastard ganister.

The *Crowstones* of Cheshire consist chiefly of white or greyish sandstones of much coarser texture than the ganisters. In that at Mow Cop, Cheshire, the grains are rather coarse (up to 2 mm. diameter), and contain a fairly large proportion of sericitic matter and clay in the interstitial cement.

At Kidsgrove, near Stoke-on-Trent, the beds are much finer in texture, the average grain size being 0·5-0·8 mm., whilst a considerable proportion of smaller grains from 0·1-0·2 mm. fill up the interstices. Felsite and chert also occur in this rock. The crowstones at Congleton and Burslem are still finer-grained, and are somewhat deeply iron-stained in places; felspar and mica are much more common in the Congleton rock than in the other parts of the beds.

The crowstones are used chiefly for the production of silica-cement and silica-sand, as well as fine-grained silica-powder. At Burslem they are used for the production of silica bricks and ground ganister.

The Cefn-y-fedw sandstones appear to belong to the Millstone Grit rocks; they consist of more or less silicified sandstones, which in places are really quartzites. At Bwlchgwyn the white and tough quartzite, stained to a purplish colour near the surface and somewhat iron-stained at the joints, is worked for making silica bricks. It is fairly fine-grained, the particles being up to 0·3 mm. diameter, and associated with a moderate proportion of cherty matter. It is very free from impurities, containing no felspar or mica and only a small proportion of iron compounds. At Llangollen the texture is very fine, the grains being between 0·1 and 0·15 mm. diameter.

At Trevor, near Ruabon, and Ffrith, near Wrexham, the rock is coarser in grain, the particles being up to 0·3 mm. diameter, whilst at Garth Mine, near Ruabon, grains up to 0·8 mm. diameter occur. Felspar, felsite, and chert occur in varying proportions, and at Llangollen some carbonates are present in the cement, which contains much interstitial matter. Kaolinitic matter occurs at Trevor, where the rocks are also rather felspathic. At Garth Mine, mica, chlorite, and limonite, as well as kaolinitic matter, occur in appreciable proportions.

The Cefn-y-fedw sandstone is used chiefly for the manufacture

of silica bricks and ganister mixture ; at Erith Works, near Mold it is used for the production of abrasive soaps; whilst at Hafod, in the same district, it is used for silica flour, as well as being dressed and used in its natural state for furnace linings.

The siliceous sandstones of Lanarkshire and Stirlingshire consist of whitish and micaceous rocks, generally fine-grained, and cemented partly by siliceous material and partly by clay. They are used chiefly for the manufacture of silica bricks.

The " Rotten rocks " of the Millstone Grit Series (p. 48) are of the same nature as those in the Carboniferous Limestone (p. 150), but are somewhat finer in texture. According to Boswell, the Garngad sand contains 60·9 per cent of grains between 0·1 and 0·5 mm., whilst the sand from the Inchneuk Quarry, Glenboig, contains 86·9 per cent between these limits.

A pure white sandstone, containing at the top about 97-98 per cent of silica, which occurs above the ganister at Falkirk, has been suggested as suitable for the hearths of open-hearth furnaces.

At Levenseat, Scotland, there is a bed of soft yellow or brownish sandstone about 80 ft. thick, which is readily disintegrated into loose sand containing a fairly large proportion of ferruginous matter and clay, largely removed by washing, the product being a sand of creamy colour, which darkens on burning, but contains, according to Boswell, over 99 per cent of silica and about 0·03 per cent of iron oxide. The proportion of heavy minerals is generally less than 0·1 per cent, and consists chiefly of ilmenite, leucoxene, zircon, rutile, and tourmaline. According to Boswell, the texture of this sand is quite uniform, over 88 per cent occurring between the sizes 0·25 and 0·5 mm. diameter, and 6 per cent between 0·1 and 0·25. About 1·6 per cent of " clay " is present in the natural material. In the washed product, nearly 95 per cent of the material lies between 0·25 and 0·5 mm. diameter. This sand is chiefly used for common glass-ware, but it is also suitable for lining open-hearth furnaces.

The *Lower Coal Measures* yield many sandstones which are valuable as refractory materials. These are usually classed as bastard ganisters (p. 107), but some are really siliceous sandstones.

The Guiseley rock at Guiseley, Yorks (p. 49), is a white quartzitic sandstone of fine grain, the particles being generally about 0·1-0·15 mm. diameter, cemented by a siliceous cement, with which is associated a considerable proportion of heavy detrital minerals, including, according to Boswell, garnet, anatase, ilmenite, rutile, zircon, limonite, and leucoxene. Some parts of the beds are almost free from mica, whilst others contain it in moderately large flakes. The beds are practically non-felspathic. An analysis by Boswell shows 97·5 per cent of silica, with 1·8 per cent of alumina and about 0·09 per cent of iron oxide, together with a little lime ; and a mechanical analysis by him shows that the crushed rock contains 40 per cent of grains between 0·25 and 0·5 mm. diameter, and about 44 per cent is between 0·1 and 0·25 mm. and nearly

10 per cent between 0·01 and 0·1 mm. diameter. More than 6 per cent of "clay" is also present. This rock is used chiefly as "ganister" and for making silica bricks.

The cream-coloured sand of Ballycastle, Ireland, which contains, according to Boswell, nearly 99 per cent of silica and only about 0·02 per cent of iron oxide, is derived from a soft white or creamy-coloured sandstone which occurs in a bed about 60 ft. in thickness above the Main Coal of the Lower Carboniferous strata. Boswell has found that this sand is quite uniform in texture, about 83 per cent of the grains being between 0·25 and 0·5 mm. diameter, together with about 12 per cent between 0·1 and 0·25 mm. diameter. There is seldom more than 1 per cent of "clay." The total proportion of true sand is very high, being between 98 and 99 per cent.

In the *Middle Coal Measures* are several sandstones which are worked as sources of sand for refractory and other purposes; the most important are the following:—

The *Ketley sandstone* of the Middle Coal Measures of Shropshire is a very soft pale-coloured stone, which is readily powdered between the fingers. It is fairly fine, and consists chiefly of grains between 0·2 and 0·3 mm. diameter, the particles being largely coated with ferruginous and other impurities. It is used for the manufacture of silica bricks, and is also ground to produce a sand for lining re-heating furnaces.

Gornal stone is a pale, buff-coloured powdery rock consisting of grains between 0·2 and 0·5 mm. diameter, of quartz, together with chert and decomposed felspar, sericitic and kaolinitic material. Iron compounds are evenly disseminated through the rock, and are generally present only to a moderate extent. This stone, when reduced to powder, is used as cupola sand, "best white sand" for gas-works, and as a scouring sand. A so-called ganister which lies below it is used for wall-plastering and as ground ganister.

The sandstone of the Middle Coal Measures at Riddings, near Alfreton, is pale grey in colour and fairly fine-grained, containing some mica, clay, and calcite. It is used together with ganister sand for the manufacture of silica bricks.

Triassic sandstones.—The *Rhaetic* sandstone at Morriston, Glamorganshire, is of a greenish-grey colour, and consists of particles from 0·15 to 0·2 mm. diameter, associated with chert, felsite, microcline, and other felspars. The rock is rather friable; it is used for making silica bricks, and when ground it is also used for furnace linings.

Bunter sandstones which are of commercial value are usually soft and friable, and are dealt with under *Bunter Sands* (p. 85).

Jurassic sandstones are sometimes used as sources of sand for refractory and other purposes. Thus, the sandstone below the Castleton ganister in the Estuarine Series, near Sheffield, is of a buff or yellowish colour and is fairly soft, consisting of grains from 0·05 to 0·1 mm. diameter, set in a partially ferruginous and partially siliceous cement, which contains various impurities in

addition to iron, including mica and chlorite. It is used chiefly as a casting sand in foundries. The freestone below it is rather coarser, consisting of grains from 0·2 to 0·3 mm. diameter, and containing more felspar and mica, as well as iron compounds, including limonite and carbonaceous matter. It is brownish in colour and speckled with impurities. It is used in conjunction with the yellow sandstone as a foundry moulding sand.

The sandstone occurring below the Hard Ganister at Commondale consists of soft white or yellowish rocks, the top beds being of greatest purity. It is chiefly ground to produce silica sand, which is used for the hearths of open-hearth furnaces and for patching purposes. A silty rock of very fine texture also occurs in the same beds, and is used for casting iron.

White flint is the name given to a sandstone which occurs above the Hard Ganister at Commondale, and also at Deepcar, near Sheffield, and at Meltham, near Huddersfield. It is very hard and of a pale grey colour ; the grains are generally about 0·15 mm. diameter, and are cemented chiefly by siliceous material, which occurs in considerable proportions. Felspar and mica occur only in very small proportions. At Deepcar it is rather finer in texture than at Commondale, and is of a buff colour. Rutile and zircon are specially abundant.

At Meltham, near Huddersfield, the " white flint " is similar to the Commondale rock, but is of a pale buff colour, on account of the iron oxide present. This rock is used chiefly for the manufacture of silica bricks at Deepcar and Huddersfield. The rock at Commondale is not at present used to any great extent ; its use for silica brick-making has been attempted successfully, but only on a very small scale.

Santorin Earth is a siliceous, volcanic ash found on the Greek island of Santorin. It is similar to *pozzuolana* (p. 136) and *trass* (p. 165), but contains rather more silica and less alumina. It is used in place of part of the sand in waterproof concrete, as it combines with the lime set free when Portland cement is wetted, and forms therewith a fresh cementitious compound.

Schists are crystalline rocks having a characteristic structure composed of more or less closely-parallel layers or folia, consisting of one or more minerals, either in distinct or alternating laminae, or intermingled in no definite order. The texture is somewhat similar to that of stratified rocks, but the layers are not continuous and are often broadened out into lenticles. They are frequently contorted and sharply curved, this structure being particularly evident under the microscope. The layers are not readily detached from each other, but form a tough and not easily fissile mass.

Schists are usually named by some characteristic mineral which they contain, as mica-schist, chlorite-schist, hornblende-schist. Mica-schists must not be confused with micaceous sandstones, which also contain numerous laminae of mica and are easily split up into flakes. Such a structure, though similar, is not truly

e, being due merely to the mode of settlement and not to
sation *in situ*.
sts have been formed by the action of various metamorphic
es, particularly pressure upon sands and clays. They
iefly in the Highlands of Scotland and the North of Ireland.
re sometimes used for the manufacture of silica bricks,
generally they are unsuitable for this purpose.
Port-a-cloy rock found near Stonesfield (Co. Mayo) consists
ecomposed quartz-mica schist, which, according to H. F.
d, has the following analysis :

Silica	76·47 per cent
Alumina	12·66 ,,
Titanium oxide	0·31 ,,
Ferric oxide	1·82 ,,
Lime	0·12 ,,
Magnesia	0·45 ,,
Potash	5·05 ,,
Soda	0·31 ,,
Loss on ignition	2·94 ,,

ording to Boswell, it contains numerous grains of rutile,
e, zircon, chlorite, muscovite, and mica, whilst about half of
shed material consists of grains between 0·25 and 0·5 mm.
er, together with nearly 30 per cent between 0·1 and 0·25 mm.
er. About 3 per cent of coarse grains between 0·5 and 1 mm.
er and nearly 4 per cent of " clay " are also present.
Sand is produced by marine deposition, but it is largely
from the action of glacial, fluviatile, estuarine, and aeolian
The common idea is that sea sand is chiefly produced by
sive action of the sea on the coasts, but this is improbable.
and is certainly produced by this means, but the greater
the sea sand appears to have been delivered as sand to the
l accumulated by various agencies along the shores. (See
Sands, p. 157.) Nine-tenths of the world's coasts being
ith sandy beaches, there must be an omnipresent source
ly, far greater than the direct effect of sea-water on the
Moreover, large sandy beaches occur at the foot of many
nes made of materials which do not produce sand.
sand is usually yellowish in colour, though at the junction
rivers with the sea it is almost white, as *Calais sand*. The
re varieties contain much iron, sometimes a large proportion
chalk, and almost invariably some salt. The latter can
be completely removed by washing, so that sea sand cannot
l where this ingredient is harmful. Many sea sands also
a considerable proportion of organic matter, together with
ains of living organisms, such as shells. They also contain
large variety of different minerals, though the proportion
is often too small and too variable to determine accurately.
ondary Sands are those which have been carried away by
or other denuding agency from the place where they were

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originally formed and have been re-deposited. They are usually purer than primary sands, on account of the classifying action of the wind or water which has transported them to the new situation. Thus the heavy minerals present will be eliminated to some extent, unless they are very fine, as a current of air or water capable of carrying grains of quartz of a certain size will only be able to carry very much smaller grains of heavier minerals, so that the larger grains are left behind. There may also be a considerable amount of classification with reference to the sizes of the grains.

Sedimentary Sands are identical with secondary sands, and owe their name to the fact of their first being suspended in water and then allowed to settle, forming sediments. They are sometimes termed " transported " sands.

Shell Sands contain a large proportion of comminuted shells, and are generally found on low, shelving coasts exposed to prevalent on-shore winds. In some places they are consolidated into a hard mass by the solution and re-deposition of lime around the shell grains. Shell sands are used to some extent by farmers for dressing land, the calcium carbonate present enriching the soil. (See also p. 35.)

Shore Sands are those occurring along the sea coasts in the form of beaches, dunes, etc., and may be produced either by (*a*) the disintegration of rocks along the sea coast ; (*b*) the accumulation from some other locality of material from disintegrated rocks, brought to its present situation by marine action ; (*c*) materials reduced to powder by fluviatile or glacial action and transported to the sea, from which they are thrown back on to the shore ; or (*d*) the accumulation of loose material as a result of wind or aeolian action. Sands belonging to section (*d*) are further dealt with under the heading *Blown Sands* (p. 82).

Most beaches are formed of sands accumulated by methods (*a*), (*b*), and (*c*), but they are augmented by blown sand (*d*). The occurrence and distribution of shore sands are dealt with on p. 77.

The colour of shore sands varies from almost pure white to dark brown, through various shades of grey, yellow, and brown. There are no pure white sands of this type in the United Kingdom which are present in sufficient quantity to be commercially useful. Grey sands, according to Boswell, occur at Ballyphetrish, Tiree, Clonakilty, Co. Cork (Ireland), Laig Bay, Eigg, and Laggas Bay, Islay (Scotland) ; these contain very small proportions of iron oxide, though, on burning, they turn a rather darker colour. The sands of Ardara, Co. Donegal, vary from pale to yellowish brown, whilst those of Ballycastle and Portrush (Co. Antrim), Coalisland (Lough Neagh), Machrihanish Bay, Millisle, Co. Down, and Sutton, Dublin, are also brownish in colour. They mostly darken slightly on burning, on account of the oxidation of the ferrous iron compounds present.

The chemical composition of shore sands varies considerably, depending on the nature of the rocks from which they have been

the character of the actions resulting in their accumulation, ıy other factors. The purest shore sands occur, according .ell, in the Isle of Jura, and contain about 0·07 per cent of ˬxide and nearly 98 per cent of silica. The sand at Sandy-ınt Strand, near Dublin, used for glass bottles, contains only about 84 per cent of silica, 5 per cent of iron oxide, and nearly 5 per cent of lime.

The sands at Maghera and Sandfields, Ardara, Co. Donegal, contain about 0·7 per cent of iron oxide, as well as a considerable amount of calcareous shells and heavy detrital minerals.

The texture of shore sands varies considerably. According to Boswell, the best qualities contain over 90 per cent of grains between 0·25 and 0·5 mm. diameter; the beach sand of the Isles of Jura and Eigg contain over 95 per cent of grains between these sizes, whilst the sands of Maghera, Co. Donegal, Portrush, Co. Antrim, and Camas contain over 98 per cent. A few sands contain a larger proportion of coarser grains, as at St. Ives, where 16 per cent of the grains exceed 0·5 mm. diameter.

A variable proportion of grains less than 0·25 mm. diameter also occurs in various shore sands. Thus, Boswell found that the sands of Sandfields, Co. Donegal, and Ballycastle (Ireland) contain nearly 16 per cent of grains between 0·1 and 0·25 mm. diameter; whilst at Clonakilty, Co. Cork, about 22-24 per cent of grains within these limits is present; and at Machrihanish Bay, Ballyphetrish, and Laig Bay (Isle of Eigg) there are respectively 30, 34, and 15 per cent of the finer grains. The sands of Sandymount Strand, Dublin, Laggas Bay, the Isle of Islay, and at Millisle, Co. Down, consist, according to Boswell, largely of fine grains between 0·1 and 0·25 mm. diameter, the first containing about 65 per cent, whilst the other two contain between 70 and 80 per cent of these grains. He found that the proportion of "clay" is usually quite low, and seldom exceeds about 1·5 per cent. At Aberdeen, however, it is nearly 3 per cent, and at Maghera Green (Ireland) 8 per cent occurs.

Shore sands are used for various purposes. The English shore sands are too impure and too variable in composition to be used for any purposes other than those for which a crude and impure sand will serve. Some of the Irish shore sands are, on the contrary, sufficiently pure to be used for glass manufacture. The poorer qualities are used for building purposes and where a material of great purity is not essential.

Silica Flour is finely divided silica sand or crushed quartz, which is used for various purposes, including the facing of dry-sand moulds so as to give a smooth surface to the castings, as a filler and detergent in the manufacture of soaps and cleansing powders, in metal-polishes, etc.

A small quantity of silica flour is sometimes used in the manufacture of silica bricks where a dense structure is required. Silica flour is also used as an abrasive and in the manufacture of ultramarine.

Silica Rocks are largely used as sources of sand where a suitable

incoherent sand is not available. They may be divided into four classes:

(i.) Quartzites and schists. (See *Quartzites*, p. 138, and *Schists*, p. 155.)
(ii.) Silica rocks, sandstones, and grits (p. 147).
(iii.) Ganister (p. 104).
(iv.) " Amorphous " quartzites having extremely fine grains (p. 143).

Siliceous Sinter is a form of hydrated silica, also known as *geyserite* and *Kieselsinter*; it is produced by the precipitation of silica from solution around hot springs, etc., where the solution comes into contact with the air. It may occur as crumbling and earthy, compact and flinty, or finely-laminated and shaly deposits. It may be dull and opaque or translucent, in the latter case having a pearly or waxy lustre. When pure, it is snowy white in colour, but is often tinged with yellow or pink. It consists of 84-91 per cent of silica, together with small proportions of alumina, ferric oxide, lime, magnesia, and alkali, and from 5 to 8 per cent of water. In Iceland, a bed of siliceous sinter is said to be six miles long, nearly a mile wide, and a hundred feet thick; whilst in the Yellowstone Park, America, similar enormous beds occur.

Silt is a detrital material produced by fluviatile, lacustrine, or glacial action, and consists mainly of very fine sand and granular non-plastic materials, together with a greater or less proportion of clay. Seger defines silt to be that portion which may be washed away by water travelling at 0·7 mm. per second. This corresponds to particles between 0·01 mm. and 0·025 mm. diameter, but Boswell defines it as 0·01-0·1 mm., dividing the sizes into (*a*) fine silt, consisting of particles between 0·01 and 0·05 mm., and (*b*) coarse silt, which consists of particles 0·05 to 0·1 mm. diameter.

Silt may be composed of either fine calcareous or siliceous material, together with a variable proportion of clay, according to the nature of the rock from which it is derived. It is sometimes known as *dump* or *duff*.

The Humber silt has been successfully used for making bricks, many of which have been used for Grimsby docks and town. It is of a dark blue colour, which soon, from exposure, changes to brown. On burning, the bricks vary from a dark purple to a dirty white, passing through various shades of blue, red, and yellow in a space of two or three inches.

The slime or silt from the River Parrett is used in the manufacture of bathbricks, an important household abrasive and cleansing agent.

Silver Sand is a fine white sand which owes its name to its supposed silvery appearance. It is found in small quantities in many localities in the form of "pockets" in clay beds. Large quantities of silver sand are imported from France as ballast for returning vessels, and for that reason it is often known as Calais

sand, though it need not have been quarried near Calais. It is largely used in agriculture for opening up heavy soils, as a coarse abrasive, for scouring purposes, glass manufacture, as a source of silica in various chemical industries, and generally for all purposes hich a pure silica sand is used. The appearance of silver sand ften misleading, as it gives the impression of being a very pure sand, though this is by no means always the case. (See *White Sands*, p. 168.)

Soil is that portion of the uppermost layer of the earth's surface which is in a sufficiently loose state of division to be suitable for the growth of plants. It consists of the finer mineral particles produced by the action of the weather on rocks, together with decayed animal and vegetable matter—that is, of a mixture of sand and clay, with or without other materials,—and is exceedingly varied in character. Soil is usually formed by the growth of vegetable matter on the weathered upper surfaces of rocks. Apart from the disintegration of a rock at the surface, little change may take place until plants commence to grow in it. The decayed vegetable matter becomes mixed with the rock residue and forms what is known as soil or earth. The organic substances dissolved in the water, percolating through this soil and descending to the rocks below, aid further in disintegrating the rock.

A section through a soil bed and the rock below would show a continuous gradation between the soil above and the solid rock below, passing from the sandy subsoil through pebbles and large stones until finally the undecomposed rock occurs. In Great Britain the soil forms a layer from a few inches to more than a foot thick, and below it lies the rock, with an intermediate material —the subsoil—between them. There is frequently a strong resemblance between a soil and the rocks on which it lies, but great differences between them exist so frequently that it is impossible to lay down any definite rule for their comparison.

In some cases, soils are formed by material which has been transported either by water or by wind from some other locality and deposited.

Dust and sand may be intercepted by plants, etc., and gradually descend to the soil below or be washed down by rain, increasing the thickness of the soil. Thus the rich soil of the plains of China, termed "loess" (p. 125), is partly the result of the deposition of blown detritus. In Central Asia the air is sometimes thick with a fine yellow dust, which, in Khotan, is sometimes so thick as to obscure the light of the sun. This dust gradually settles and forms a valuable soil, rendering the land very fertile.

The action of the various natural agencies at work in the disintegration and weathering of rocks has already been described (Chapter I.). Soils are termed "sedentary" when they have been formed by the simple disintegration of the rocks on which they rest, and "transported" when they have been carried to other places by water, ice, or wind.

Soils are divided into four chief groups, according to their main constituent: (*a*) argillaceous or clay soils; (*b*) arenaceous or sandy soils; (*c*) calcareous or marly soils; and (*d*) humic or peaty soils.

The soils which most interest the reader of this volume are class (*b*), and these may be divided into three sections:

(i.) Sandy soils containing 80 per cent or more of sand.
(ii.) Loamy sands containing 70-80 per cent of sand.
(iii.) Sandy loams containing 60-70 per cent of sand.

Soils containing large proportions of sand are very porous, friable, and light or "open," and are very valuable for certain branches of agriculture. (See Vol. II., Chapter VIII.)

The nature of the soil depends on the rock from which it has been derived. Tulackoff classes soils as follows:

1. Laterite soils, developed in humid, tropical climates, and marked by a high proportion of hydrated ferric oxide and alumina.
2. Wind-blown, or loess soils.
3. Soils of dry steppes, rich in soluble salts, often alkaline.
4. Black soils (Tchernozem), rich in neutral humus.
5. Grey forest soils, with less humus.
6. Peaty and ashy soils, including all the soils of Great Britain.
7. Tundra soils.

The effect of sand in soil is described later in Vol. II., Chapter VIII.

To the agriculturist the soils derived from sedimentary rocks are of greater value than those produced by the disintegration of igneous rocks. The alluvial deposits are soils in themselves and may vary from light silty soils to heavy clayey beds, or they may be composed of peaty matter. Soils produced by glacial action are very variable in character and usually are rich in clay and stones—often of limestone. Such soils occur especially in Norfolk and Suffolk.

The Eocene soils are very valuable and are largely utilised around London, though in some cases, for example in the Bagshot sand, the soil is very poor and almost worthless for agricultural purposes. The Eocene beds yield the heavy London clay which is a valuable soil for some purposes, but in the south of Hampshire they are very poor and sandy.

The Chalk soils are thin, whitish, and poor, and are chiefly employed for pasturage.

The Upper Greensand gives a dry, porous and limey soil of moderate fertility but sometimes rather thin.

The Gault gives a cold, sticky, brownish soil of little value.

The Lower Greensand soils vary greatly in character from a very fertile land to that which is almost barren, these changes in character often occurring within very short distances.

Weald formation gives a stiff, yellow soil which is generally poor, though sometimes very productive.

Hastings beds yield soils which are poor and sandy, whilst those on the Oolite are generally somewhat clayey and calcareous.

The Portland beds and Coral Rag give thin, calcareous soils, though occasionally rich sandy loams are found which are very productive.

The Kimmeridge clay beds give excellent pasture soil of a stiff clayey nature, and the Oxford clay is somewhat similar, being rather difficult to work and sometimes poor.

The Cornbrash beds give calcareous soils, as do also the Forest Marble and the Great and Inferior Oolites.

The Lias beds give light soils of very good quality, which are excellent for arable purposes.

The Trias soils are somewhat porous loams which are excellent if not too porous.

The Permian rocks give light, dry soils, which are generally fertile.

The Coal Measure soils may be either light and sandy or very heavy, whilst in some places a mixture forms a very useful, fairly light soil.

The Millstone Grit rocks form very thin and poor, sandy soils, and are often waste moorlands. The Carboniferous Limestone gives a thin, calcareous soil which is deeper and richer in the valleys.

The Old Red Sandstone weathers to a rich and deep soil of great value, though in some parts it is very sandy. It is also frequently calcareous.

The Silurian formation gives cold, clayey, or sandy soils, though in some parts it is fairly fertile.

The Cambrian and Laurentian rocks give good soils at low elevations, but at higher ones they are poor and sandy.

Igneous rocks generally give very thin and poor soils except in the valleys, where good soils are sometimes found. In some places granite gives a very fertile soil.

In general, the harder rocks produce very thin and poor soils, whilst the softer rocks give deeper and richer soils. Clay rocks, of course, give clayey soils, whilst those produced by the disintegration of sand rocks are more sandy and lighter.

Standard Sand is a term applied, especially in connection with the manufacture of concrete, to a sand used for comparing the binding power of various cements, and, conversely, as a means whereby the suitability of other sands for concrete may be judged. For this purpose, any other sand is required to possess as closely as possible the same qualities as the standard sand. The British standard sand is obtained from Leighton Buzzard, whilst the American standard sand is obtained from Ottawa, Ill. Both the British and the American standard specifications for cement require the use of a sand of 20- to 30-mesh, *i.e.* composed wholly of particles 0·016 to 0·025 mm. diameter, though the British sands used in

concrete do not always conform to this specification. The American standard specification demands sand consisting of rounded grains, whilst the British standard specification mentions the Leighton Buzzard sand, which is subangular.

The standard sand in France is obtained from Leucate, the particles being between 1·5 mm. and 1 mm. diameter (0·04 to 0·06 in.). A compound standard sand is also used in France consisting of equal parts of sands of the following grades: (*a*) 2 mm. to 1·5 mm., (*b*) 1·5 mm. to 1 mm., and (*c*) 1 mm. to 0·5 mm.

In Germany a standard sand is used which is very similar to the British standard, but the German sand must not exceed 28-mesh as compared with the 20-mesh in this country.

The standard sand used in Austria is also similar to the British standard sand.

Subsoil Sands are the arenaceous deposits formed by the disintegration of rocks, and, when mixed with decayed vegetable and carbonaceous matter, form the soil which covers the surface of most parts of the earth.

The colour is usually yellow or reddish, due to the presence of hydrous ferric oxide (limonite), which is an important colouring agent in nearly all weathered materials which do not contain any appreciable proportion of organic matter.

Tar Sands, see *Oil Sands* (p. 131).

Terrestrial Sands are those formed on land surfaces as the result of the disintegration of pre-existing rocks. They may be classified, according to Lake and Rastall, as follows :

Residual : gravels, sands, wacke, laterite, etc.	Sedentary.
Colluvial : talus and cliff débris.	Transported.
Alluvial : alluvium and swamps, and some loess.	
Aeolian : wind-blown sand and some loess	
Glacial : moraines, drumlins, eskers, etc.	

Thanet Sands occur at the base of the Eocene formation in the north of Kent and in the Isle of Thanet, from which the beds are named. Their occurrence and distribution are described on p. 67. They vary in colour from grey to pale brown. At Charlton, in Kent, the top beds consist of clayey sands, known commercially as " Blackfoot " or " Erith " sand, and are used as moulding sand in foundries and steel works. The paler beds contain, according to Boswell, about 95 per cent of silica and 2·4 per cent of alumina, together with about 0·42 per cent of iron oxide and a small percentage of lime. The principal detrital impurities present include ilmenite, leucoxene, limonite, zircon, rutile, tourmaline, staurolite, andalusite, and muscovite. The sand is very fine, containing, according to Boswell, nearly 80 per cent of grains between 0·1 and 0·25 mm. diameter, together with about 16 per cent of grains between 0·25 and 0·5 mm. diameter. A small proportion of " clay " is also present, but it does not usually greatly exceed 1 per cent. The Charlton sand is used chiefly for ordinary bottle-glass.

ı the Thanet beds at Bramford, near Ipswich, a dark-green ..uconitic sand occurs which, according to Boswell, has the following composition :

Silica	60·61
Alumina	9·73
Titanium oxide	0·70
Ferric oxide	9·67
Ferrous oxide	0·45
Lime	1·22
Magnesia	1·89
Potash	2·98
Soda	0·33
Phosphoric acid	0·13
Loss	12·38

It is not at present used, but it might be useful as a source of potash.

Thorium Sands, see *Monazite Sands* (p. 128).

Till is a term synonymous with Glacial Drift, though it is usually applied only to the plastic clayey portion of the Drift.

Tin-bearing Sands and Gravels are produced by the concentration of cassiterite obtained by the decomposition and disintegration of granite rocks. The cassiterite is usually associated with tourmaline, topaz, axinite, garnet, wolfram, scheelite, limonite, magnetite, and other heavy minerals, these, including the tin, tending to become concentrated at the bottom of the deposit. The sand itself is largely composed of tourmaline-bearing quartz. The greater part of the world's supply of tin is now obtained from the tin-bearing gravels of Malaysia, where it is associated with ilmenite, arsenopyrite, wolfram, monazite, topaz, and tourmaline, but is readily separated by methods which are based on the tin ore having a much greater specific gravity than that of the other minerals associated with it.

Tin also occurs in the islands of Banka and Billiton, in the Dutch Indies, in Siam and Burma, in Western Australia, Tasmania, Southern Nigeria, Bolina, Swaziland, and the Transvaal, in Africa, and in Cornwall, England. Near St. Austell a tin-placer 5-6 ft. thick occurs beneath beds of gravel, sea-sand, clay, and peat from 40-44 ft. thick, and resting upon the solid rock. These beds also contain microscopic particles of gold derived from lodes of copper and iron-pyrites.

Titanium-bearing Sands are alluvial deposits containing titanium in the form of rutile (titanium oxide, TiO_2). These deposits have been formed by the weathering and disintegration of dyke-rocks rich in rutile, aided by the subsequent concentrating action of water. Titanium also occurs as ilmenite (titanate of iron, $FeTiO_3$) in the black sands which occur in different parts of the world, on beaches, and on river banks. The black sands of the St. Lawrence river are titaniferous and have been derived from the gabbros which abound in the district. Many of the concentrates of tin and monazite sands are also rich in ilmenite. Those in Travancore

contain over 50 per cent of ilmenite which may be recovered, as a by-product, in the magnetic concentration of the monazite.

Tosca is a **pozzuolana** (p. 136) or volcanic ash found at Teneriffe in the Canary Isles. It is used chiefly in Spain as a superior substitute for part of the sand in mortars and concretes.

Trass is a powdery volcanic **tuff** or scoria consisting of consolidated volcanic ashes. The name was first applied to a material occurring in the valleys of the Brohl and the Nette, two streams which discharge into the Rhine. Trass was introduced into this country from Holland and was known as "Dutch Tarrass." It occurs in many other countries, sometimes in an earthy mass and sometimes as a rock. Both forms may be used, the rock being in some places superior to the earthy form, whilst in others the earthy form is the better.

Trachyte- and leucite-tuffs are very similar in composition and properties to trass.

Table XXIII. gives typical analyses showing the composition of trass:

TABLE XXIII.—ANALYSES OF TRASS

	Silica.	Alumina.	Ferric Oxide.	Lime.	Magnesia.	Potash.	Soda.	Water.
Dutch trass .	46	21	12	3	..	5		13
Trachyte tuff .	63	21	4	1	1	3	3	4
Leucite tuff .	67	11	5	8	3	1	1	3

The important ingredient of trass from a technical or commercial point of view is the free silica, possibly also some free alumina, which combines with the lime set free when Portland cement is wetted, or with the wet lime in ordinary mortar, to form a cementitious material. This portion of the silica is seldom indicated in a chemical analysis, though it is the only active ingredient in trass, all the other materials being of an inert nature.

Trent Sand is a sand obtained from the river Trent, and is used in the building trades and for polishing. Similar sands from the Severn and in other rivers in this country are used for the same purpose and are occasionally sold as "Trent sand." It is an ordinary river-deposited sand of medium grade, excellent as an abrasive and polishing agent, but not sufficiently pure to be used as a source of pure silica, or for glass manufacture, etc.

Triassic Sands comprise the Bunter and the Keuper sands, which may vary in colour from white to brownish, and are of widely different texture in different localities. Their occurrence and distribution have already been described in Chapter I. (See also *Bunter Sands*, p. 85, and *Keuper Sands*, p. 123.)

Tripoli is a variety of kieselguhr or diatomaceous earth (p. 96)

which is found in Tripoli and Bohemia. It is more compact than the material in most diatomaceous beds and is somewhat laminated in character. It is chiefly used as an abrasive for fine polishing, but it is also employed as an absorbent in the manufacture of high explosives and to a limited extent in the manufacture of porous plates and filtering media.

Tuff or **Tufa** consists of volcanic ash which has been consolidated by pressure into a rock of varying hardness. It is found in the vicinity of most extinct and active volcanoes, and is sometimes ground to powder and used in the preparation of hydraulic mortars, including *pozzuolana* and *trass* mortars or cements. In many ways it resembles *trass* (p. 165), but contains less active material (soluble silica).

Peperino is a dark-brown earthy granular tuff found near Rome and containing crystals of augite, mica, leucite, magnetite, and fragments of crystalline limestone, basalt, and leucite-lava. *Palagonite-tuff* is a bedded aggregate of dust and fragments of basaltic lava containing angular pieces and minute granules of pale yellow, green, red, or brown altered basalt glass called palagonite. It is found in Icelandic and Silician volcanoes, at Eifel, Nassau, Auvergne, Scania, Faroë Isles, Canary Isles, New Zealand, etc., and also in the Carboniferous rocks of Central Scotland. *Pelitic tuff* is a volcanic ash composed of minute particles of volcanic detritus, basalt, and microlites. It is obtained mainly in deep-sea dredgings ; the quantity available is far too small to be of serious commercial value. (See also *Pozzuolana*, p. 136.)

Tungsten-bearing Sands are alluvial deposits containing tungsten, as wolframite (tungstate of iron and manganese ($FeMnWO_4$), such as the sands and gravels of Southern Hunan, Southern Kwangsi, and Kwantung in China, from which deposits most of the Chinese tungsten ore is obtained. Wolframite also occurs in alluvial deposits in the hill slopes in Burma and in the Malay States.

Scheelite (calcium tungstate, $CaWO_4$) occurs in deposits formed by the surface weathering of limestone with intrusive granites in the Kinta Valley, Malay States, from which locality it can be readily obtained.

In Arizona, wolframite and scheelite, together with hubnerite (tungstate of manganese ($MnWO_4$) with iron), occur in the Dragoon Mountains. These deposits are very rich and yield a concentrate containing 70 per cent of tungstic oxide.

In England, wolframite occurs in association with cassiterite in the alluvial deposits of Bodmin Moor, which have been derived from the disintegration of the pegmatite veins which traverse the granite in this district.

Vitrifiable Sands are those in which some of the constituents melt at a relatively low temperature and produce a dense, impervious, or even glassy mass. The constituents which produce vitrification in sands of this kind are principally lime, magnesia, and alkalies, all of which combine with the silica and form fusible silicates, which

melt to a glassy mass. If these constituents are in excess they are injurious, as they produce too fusible a mass.

Vitrifiable sands vary with respect to the range of vitrification according to the number and nature of the fluxes present. Thus lime shortens the vitrification range of the sand, and the time taken in producing a thin liquid glass after the lime silicate commences to melt is very small. Magnesia, on the other hand, tends to increase the range of vitrification. When several fluxes are present simultaneously, they usually effect a more active and rapid vitrification than when only one flux is present.

Where a vitrifiable sand is required, but is not available, a more refractory sand may be rendered vitrifiable by the addition of suitable fluxes, such as soda, lime, or even felspar, in the requisite proportions, so as to produce a sand which becomes fluid at the desired temperature. This is the basis of the manufacture of glass.

Volcanic Sands are usually very siliceous and consist of angular grains, as they have been subjected to much abrasion or weathering. They contain particles of all sizes up to that of a pea, together with large quantities of microlites and crystals of minerals, particles of volcanic glass, and minutely cellular fragments and elliptical ("hour-glass") particles. The finest dust is, in volcanic sands, ultra-microscopic.

The following analyses, due to Silvestre, are typical of the composition of volcanic ash and sand :

	Ash.	Sand.
Silica	50·00	49·80
Alumina	19·08	18·20
Ferrous oxide	12·16	12·42
Manganous oxide	0·40	0·45
Lime	9·98	11·00
Magnesia	4·12	4·00
Soda	3·72	3·60
Potash	0·60	0·49
Water	0·36	0·29
Phosphoric acid, Titanium oxide, Vanadium oxide, Ferric oxide	traces	traces

Wad is an earthy form of manganese dioxide, formed in low-lying districts by the decomposition of manganese-bearing minerals. It is dull black and amorphous, and often contains cobalt oxide, one variety known as *Asbolane* or *earthy cobalt* containing up to 32 per cent. Another variety of wad, *lampadite*, contains 18 per cent of copper oxide. Wad contains a large proportion of manganese dioxide and is used for making chlorine and for umber paints, whilst asbolane is used as a source of cobalt.

Warp is a mixture of sand, silt, and clay, usually of fluviatile, estuarine, or marine origin, such as occurs in the Humber district, where it is a light chocolate-coloured material of a soft, silky nature, having been produced by the disintegration of the Boulder

Clay and washed up by the sea and tides into the estuary of the Humber. It differs from the fluviatile deposits of the rivers flowing into the Humber, which are richer in sand and silt but poorer in mica. Much of the land west of the present mouth of the river Humber consists largely of warp. This material is of small commercial value ; it has been used as a brick earth, though not well suited to this purpose and very difficult to manipulate.

Wealden Sands occur in that portion of the Cretaceous System which is of fluviatile origin beneath the Weald clay. They are dealt with under the heading *Hastings Sands* (p. 121).

White Sands consist chiefly of quartz, felspar, and other colourless minerals. Heavy detrital minerals are generally absent or present in very small proportions. The fact that a sand is white does not necessarily mean that it is pure quartz, as it may contain large proportions of felspar, mica, and similar minerals. Sands composed of pure quartz are, however, white and are very valuable for glass-making and other purposes where a pure sand is needed. The pocket sands of Derbyshire, Staffordshire, and Wales are white, but contain a considerable proportion of mica and other impurities. White sands may also be produced by the bleaching action of carbonaceous matter, which reduces the iron compounds to the ferrous state and causes them to be removed in solution. White sands which develop a pinkish tinge on heating have usually been bleached in this way, but still contain some iron compounds in the ferrous state, which is oxidised on heating and produces the colour. The term *White sand* is sometimes applied to ground silica rock.

Wolfram deposits contain tungsten ore in particles of various sizes scattered through a matrix of granite and quartz. (See *Tungsten Sands*, p. 166.)

Woolwich and Reading Sands are described in Chapter I. (p. 67). They are chiefly employed for building purposes, but some are used in the manufacture of bricks, tiles, and red earthenware.

Yellow Sands generally owe their colour to the presence of hydrous iron oxide (*limonite*). In some volcanic districts where sulphur is very abundant this may give a characteristic yellow powder which might be mistaken for sand.

Zirconium-bearing Sands occur as river and beach deposits in Travancore (India), Brazil, and Ceylon, the zirconium being in the form of zircon (zirconium silicate) formed from the decomposition of pegmatite rock and syenites.

In Travancore the non-magnetic residues of the monazite sands consist almost entirely of zircon. (See *Monazite Sands*, p. 128.)

CHAPTER IV

MINERAL AND OTHER CONSTITUENTS OF SAND

At the commencement of this volume it was stated that a sand might be defined as any loose detrital granular material occurring in accumulations of various kinds as a result of atmospheric, aqueous, chemical, volcanic, or organic action, the particles being of any size between 0·01 mm. and 2 mm. diameter. Thus a sand may contain any mineral which could possibly occur in Nature as the result of some natural action. Consequently, almost all minerals which are capable of resisting the action of weather may be found in one or other variety of sand. As sands are produced by the disintegration of various igneous, sedimentary, or other rocks, their mineral constituents will be the same as those of the rocks from which they have been formed, with the exception of any minerals which may be removed in solution on or after the disintegration of the parent rock, and with the addition of any other minerals which may have been brought into the sand, as by transportation from some other locality.

Minerals other than silica (which is the chief constituent of most sands) may occur in four distinct conditions according to the circumstances under which they have been produced:

(1) **Crystalline minerals** as: (*a*) more or less regularly defined crystals, though these are rather infrequent except where sands have not been subjected to much abrasion or transportation. The crystals may be separate or associated in twos (twins) or threes (trins), according to the nature of the mineral, whilst in other cases a crystal may be built up of simple "microliths." (*b*) Amorphous particles or aggregations of particles having an internal crystalline structure. This type of grain is most common, as the exterior of the crystals has often been largely removed by attrition and corrosion due to prolonged exposure to weathering and other influences, whilst the grains in the original rock, before disintegration into sand, may not have possessed perfect crystalline form. Thus in granites and similar rocks the crystallisation of the various minerals has been largely impeded by surrounding grains, so that irregularly-shaped crystals are the result. When such a rock is disintegrated the loose grains produced will be

similarly irregular in shape, whilst at the same time possessing the internal crystalline character of the particular mineral of which they are composed. Where a sand has been produced by the disintegration of a rock which contains perfect crystals of quartz and other minerals, a large proportion of these crystals will occur in the sand, though their shape will be modified by the mechanical abrasion to which they have been subjected by the action of the water, ice, or air during transportation from one locality to another.

The fact that a mineral is crystalline in character, even though it may possess quite irregular external outlines, may be readily detected by examining it under a microscope with polarised light. With the exception of minerals of the cubic system, which are invisible in the dark field produced by crossed nicol prisms, all crystals and fragments of crystals are just as visible in polarised light as in ordinary light, whilst non-crystalline (isotropic) substances are invisible, or almost invisible, under such conditions.

A third form (*c*) in which crystals occur in sands is as "crystallites" or "microliths," which are incipient forms of crystallisation. Crystallites occur particularly in sands of volcanic origin. They consist of inorganic particles possessing a more or less definite shape, but generally without the geometrical characters of true crystals. They may appear like drops or *globulites* of an isotropic character, or they may be elliptical or have sharp corners. Others, termed *microliths*, are rod- or needle-shaped and are often in variously-shaped groups. Augite, hornblende, apatite, and felspars may occur in rudimentary forms of this kind. They are usually colourless, but may be black and opaque on account of a ferruginous coating.

Hair-like forms (*trichites*) sometimes occur, whilst various granular and fibrous grains of indefinite shape and character are also known.

In some cases minerals having the external form of another mineral which they have replaced in the rock from which the sand has been produced may occur. These are termed *pseudomorphs*. Quartz frequently replaces other minerals in rocks such as calcite, aragonite, siderite, gypsum, rock-salt, haematite, etc., and so may be found in sands having a different crystalline form to that which is usually associated with it, the silica having been brought into the rock in solution and replacing some other mineral whose crystalline form it has assumed.

(2) **Glassy or Vitreous Minerals.**—Sands sometimes contain comminuted or granular particles of "glass," particularly those of volcanic origin. This "glass" may include crystals or crystallites, or both, and may consist of several minerals fused into one homogeneous substance. This may be variously coloured, but is generally black or dark green when particles of it are examined. Very thin sections are either nearly colourless or pale brown. Such "glass" may be recognised by being isotropic to polarised light; that is to say, that at no position of the polariser is the light

passing through the grains visible. The various inclusions which may be present are rendered readily visible by polarised light.

(3) **Colloidal Minerals.**—Substances may be present in sands in the form of a jelly-like or horn-like material which may be either in its natural state or hardened into a stony mass. Chalcedony is a typical example of this form. In some cases these materials may be converted into the colloidal sol form, in which case they will remain in suspension in water for an indefinitely long period. Most sands contain only a very small percentage of colloidal matter, but this is often of great technical and industrial importance. In agriculture, for example, the thin film of colloidal matter surrounding the inert grains is the storehouse of almost all the nutriment on which the plants depend for their existence. The enormous technical importance of the apparently trifling proportions of colloidal matter in sands has not as yet been sufficiently realised.

(4) **Amorphous Minerals.**—Various substances may be present in sands as grains having no regular structure or shape, but occurring in irregular or indefinite forms such as granules, stains, or films.

Some of the minerals found in sands, and especially quartz, are very frequently found to contain inclusions of various kinds. The principal inclusions are: (*a*) cavities filled by air or gas; (*b*) cavities partially or completely filled with a liquid; (*c*) globules of glass; (*d*) crystals; and (*e*) filaments or indefinitely-shaped particles.

Cavities which are either empty or filled with gas (usually nitrogen) are very common in some minerals; they are usually of a spherical or elliptical shape and are generally very small, more than a million sometimes occurring in one cubic inch of material.

Cavities containing a liquid and having a curved, oval, or spherical shape are quite common and appear under a microscope to have sharply-defined black borders. In some cases they have a definite geometrical form. When such cavities occur in particles of quartz they are generally hexagonal in shape. They vary in size from microscopic dimensions to cavities readily visible with the naked eye, the latter being fairly common in large quartz crystals. These cavities usually contain water, but potassium or sodium chloride may be present as well as potassium, sodium, and calcium sulphates. Carbon dioxide may also be present in solution. Such cavities are seldom completely filled with liquid; they usually contain also a small bubble of air or gas.

Fluid inclusions may occur disseminated through a crystal in an irregular manner, or they may be arranged definitely along intersecting planes, as in quartz, felspars, topaz, beryl, and other minerals.

Cavities containing a pale greenish or brownish glass with several immobile bubbles often occur in crystals. They are usually aggregated in the centre of the crystal or are arranged in zones, as in felspar, quartz, leucite, and other minerals.

Crystals of various kinds often occur embedded in crystals of quartz, felspar, and other minerals; they are generally arranged

in the centre of the crystal or in zones. Quartz crystals frequently enclose grains of such minerals as rutile, haematite, limonite, pyrites, chlorite, etc., molten quartz having solidified around these minerals in a cooling mass, or having crystallised around them from an aqueous solution. The enclosed crystals may be either perfect or only partially formed. The minerals which most usually contain inclusions of this kind are leucite, garnet, augite, hornblende, calcite, fluorite, etc. A mineral enclosing other grains is usually termed a *perimorph*, whilst the enclosed grains are termed *endomorphs*.

Filaments or streaks often occur in crystals. Thus mottled patches occur in orthoclase as a result of its partial decomposition with the formation of kaolin. Decomposed magnetite enclosed in minerals sometimes produces brownish patches or discolorations. Tufts and vermicules of some green ferruginous silicates also occur.

Essential and Accessory Minerals.—The minerals in sand may be divided into essential and accessory ones, and also into original and secondary minerals. Essential minerals are the most important constituents and those which, if absent, would greatly alter the character of the sand. Thus quartz is the commonest essential mineral in sands, as it is usually the most important constituent, and if removed would altogether alter the nature of the sand. The essential constituents of any sand are always present in the rock from which the sand is derived.

Accessory minerals may usually, though not always, be regarded as undesirable impurities. They generally occur in small proportions disseminated through the sand, and are chiefly derived from the impurities or accessory minerals in the original rock, though other accessory minerals may be introduced during the transportation of the sand from one locality to another, or by the deposition of detritus from one locality amongst the particles of sand derived from another, or by the percolation of waters containing minerals in solution, which minerals eventually crystallise out amongst the grains of sand. The absence of such accessory substances would not, in most cases, adversely affect the nature of the sand and would usually, though not always, be an advantage.

As most sands have been subjected to weathering, the accessory minerals in them are invariably those which have the greatest resistance to such influences; any readily decomposable accessory minerals in the original rock would soon be decomposed and removed, so that only the most resistant minerals would remain in the sand.

Primary grains are, of course, those which have been derived from the disintegration of the original rock from which the sand was formed. **Secondary minerals,** on the other hand, are those which have been introduced into the sand some time after the disintegration of the original rock. Such additions may be due to transportation, the superposition of other minerals, or the percolation of water through the bed. Calcareous, ferruginous, and carbonaceous matters are probably the commonest secondary

minerals, though many other substances may occur. In some cases a mineral may be both a primary and a secondary constituent. Thus grains of quartz may occur in the original sand, whilst secondary quartz may be introduced by percolating waters, sometimes partly consolidating the loose sand into a sandstone or sand-rock, and sometimes crystallising around the original grains.

Secondary minerals may also be produced by the alteration of some of the original constituents of the sand with the formation of new minerals. Thus the mineral ilmenite may be partially changed into leucoxene. Ferric oxide (haematite) or magnetic iron oxide (magnetite) may be partially converted into ferrous oxide or limonite; many other similar changes may occur, the resultant products being secondary minerals.

SILICA

Silica is the commonest constituent of the earth's crust. According to F. W. Clarke it occurs to the extent of about 60 per cent of the total weight of the rocks forming the crust to a depth of about ten miles. It is an essential constituent of many igneous rocks, especially the acid plutonic rocks such as granite. It is an important constituent of many metamorphic rocks such as gneiss, schists, etc., and forms a very large proportion of the bulk of sedimentary rocks. In addition to this, it is one of the most resistant materials, and in its crystalline form, as quartz, is able to persist through weathering actions extending over an almost indefinite period of time, the only action which takes place being the rounding of the corners due to mechanical abrasion. Consequently, silica in various forms is the commonest constituent of sands, many deposits consisting almost wholly of silica.

The silica present in sands includes that which occurs as free quartz, or free silica in some other form, and also that which is combined with other substances forming silicates and alumino-silicates, such as felspars, mica, clays, etc.

Free Silica occurs in various forms in Nature, some being amorphous, whilst others are truly crystalline. Table XXIV. shows the various forms in which silica may exist in the free state:

Table XXIV.—Forms of Silica

State.	Mineral Form.	
Amorphous . .	Amorphous silica .	Precipitated silica. Silica glass.
Crystalline .	Quartz . . .	α-quartz, β-quartz.
	Tridymite .	α-tridymite, β-tridymite.
	Cristobalite . .	α-cristobalite, β-cristobalite.
Cellular . .	Cellular silica . .	Diatomaceous earth, etc.

Those forms which are designated by the Greek letter α are stable at ordinary temperatures and are most likely to occur in Nature, but where a rock has been suddenly cooled, the form designated by the Greek letter β, which is stable at higher temperatures, may not have had sufficient time to revert to the form stable at low temperatures, so that it may occur in Nature as well as the more stable α forms.

The nature of the various allotropic forms of silica is not thoroughly understood, though various theories have been put forward to explain them. The theory of W. and D. Asch suggests that the various forms of silica contain a different number of atoms of silica to each molecule, with the result that forms having different specific gravities are produced. As the specific gravities of tridymite and cristobalite are less than that of quartz, the two former, according to this theory, contain a smaller number of atoms in their molecules. Whilst it is almost impossible to ascertain the molecular weight of any solid substance, it does seem certain that all forms of solid silica must contain many more molecules than are represented by the formula SiO_2, this being a *minimum* formula. If it were correct, silica, as analogous to carbon dioxide, would be a gas instead of an almost infusible solid. Some investigations of Martin on organo-silica compounds appear to show conclusively that the ordinary laboratory form of precipitated silica must be represented by at least six times the usual formula, and Martin's experiments confirm the views of W. and D. Asch as to the hexagonal or ring arrangement as representing a minimum formula for this form of silica, which in this respect is analogous to Kekulé's famous benzene ring theory of the constitution of certain carbon compounds. An investigation of the X-ray spectra of the various forms of silica would be of great value in this connection, though their interpretation is exceedingly difficult.

The various forms of silica may very conveniently be regarded as suggested by W. Ostwald as having different degrees of dispersion, ranging from the crystalline form, such as quartz, through chalcedony, hyalite, geyserite, and soft opal to a colloidal silica gel, the proportion of water in the material varying progressively with the degree of dispersion.

Amorphous Silica occurs in sands in various forms, the chief of which are *flint*, *opal*, and *geyserite*, the last-mentioned usually occurring alone and not as irregularly-disseminated particles in other sands.

Flint is a form of precipitated amorphous silica produced by the deposition of silica around some nucleus, such as a minute shell-fish, sponge, or other organism, or around some inorganic substance. By prolonged deposition, irregular nodules of a grey or black colour are produced, the size varying considerably. A large proportion of flints could not be classed as sand at all, but the smaller fragments which occur in some sands may be included. They do not usually consist of perfectly pure silica, but contain about

5 per cent of impurities, chiefly organic matter and chalk, the carbonaceous matter present being the cause of their dark colour. Flints are extremely hard and break with a conchoidal fracture. According to Roscoe and Schorlemmer, flint is an intimate mixture of amorphous silica and quartz or tridymite.

Particles of flint are comparatively rare in sands, though there is a bed at the base of the Thanet sand containing a large proportion of angular chips, showing a minutely granular structure under crossed nicols, and giving a dark colour to the sand; in some places, particles of altered black flint occur. Flint is more frequently found in recent sands than in those of considerable age.

Chert, or hornstone, is an impure variety of flint formed by the deposition of sponge spicules. It is truly amorphous, but in some cases it appears almost as if it were crystalline. In colour the grains are grey, brown, or black, and they have a flat rather than a conchoidal fracture. Chert is common in sands of all ages and is a frequent constituent of the Carboniferous rocks; it also occurs in the Leighton Buzzard and Huttons Ambo sands.

Chalcedony is an opaque variety of amorphous silica and is somewhat fibrous. This also, according to Roscoe and Schorlemmer, is an intimate mixture of amorphous silica and quartz or tridymite. Like flint it is generally formed around a nucleus of some foreign matter. It is very hard (7 according to Mohs' scale), has a specific gravity of 2·55-2·58 and a refractive index of about 1·54, which is rather lower than the refractive index of quartz; the birefringence of chalcedony is also somewhat lower. In colour it varies from white to bluish-white or brown. It contains combined water, which is evolved when it is heated to 100°-200° C., the evolution of steam often causing the fracture of the material. On further heating to about 600° C. it changes into quartz and finally into the lower specific gravity forms of crystalline silica (cristobalite and tridymite). There are many varieties of chalcedony, though most of them do not occur in sufficiently small grains to be classed as sands. The chief varieties are *carnelian*, *prase*, *agate*, and *onyx*.

Opal is a variety of hydrated silica similar to chalcedony and contains 5-10 per cent of water. It is considerably softer than quartz, its hardness being only 1·9-2·3 on Mohs' scale; its specific gravity is only 2·2 and its refractive index 1·45. It is optically isotropic. Opal is produced by the deposition of silica from solution in water or by the hydration of anhydrous silica.

Siliceous Sinter or *Geyserite* is a loose, porous form of amorphous silica, produced by precipitation or evaporation from its solution in water. Large deposits of this material occur around hot springs in Iceland, Yellowstone Park, U.S.A., etc.

Other forms of hydrated and amorphous silica which rarely occur in sand deposits include *hydrophane*, *hyalite*, *menilite*, *float stone*, etc.

Silica glass is an amorphous form of silica which is seldom or never found in sand deposits. The only known natural form of

this substance is *Lechatelierite*. As an artificially prepared material it is well known commercially as quartz glass or fused quartz.

Colloidal Silica is amorphous silica and includes several varieties previously mentioned, such as flint, chalcedony, etc. Colloidal silica may contain any proportion of water up to more than 90 per cent, those forms which contain the least water being harder and denser, whilst those containing more water, such as siliceous sinter, may be quite soft. On heating any form of colloidal silica, water is lost, the presence of salts rendering the loss more rapid. The dehydrated silica cannot be rehydrated again except with great difficulty, and if it has been heated to redness its complete rehydration is almost impossible, on account of the hardness of the material. Colloidal silica, as found in Nature, is chiefly in the gel form, as the more dispersed *sol* form can only exist in the presence of relatively large quantities of water and is only recognised with difficulty.

Silica, when sufficiently finely divided, so that its particles are ultra-microscopic in size, assumes in the presence of water an electro-negative charge on each particle, and if there are no interfering conditions, the minute particles of silica will persist in a rapid motion which is only limited by the walls of the vessel in which the material is contained. As a particle of silica in this active state approaches another similarly charged, the two particles will mutually repel each other, so that their motion is perpetual so long as other conditions remain constant. The motion of the particles may readily be observed by means of an ultra-microscopic examination.

Silica in this colloidal sol form is exceedingly sensitive, and if any electro-positively charged particles are added, *e.g.* water which has fallen a considerable distance through the air in the form of rain, or various solutions of electrolytes, the particles of silica will coalesce and form a gelatinous precipitate; this is the *gel* form of silica. If the gel is allowed to dry, or if it is heated, a horny form of silica is produced resembling flint, but if the temperature is still further increased, a white material is formed which is the ordinary "calcined silica" of the laboratory. Silica in the form of a colloidal gel is an important constituent of many rocks; in some it produces veins or intrusions; in others it is of considerable importance as a binding agent, and many consolidated sands are bonded by this substance.

Non-crystalline silica is more readily affected by weather than the crystalline varieties and is, consequently, more easily removed in solution, so that large masses of the amorphous varieties of silica are of infrequent occurrence, though they do occur.

Crystalline Silica occurs in sands chiefly as *quartz*, but also as *tridymite* and *cristobalite*, though the two latter occur only rarely.

Quartz is a crystalline variety of silica occurring in hexagonal or rhomboidal forms, the development of which depends on the situation in which they have been formed and the mode of formation. In sands, perfect crystals seldom occur, as in most cases the

crystals have been impeded in their formation by the juxtaposition of other crystals, so that quartz is generally found as irregular fragments having an internal crystalline structure, which may readily be seen by examining them in polarised light. There is also an absence of surfaces showing cleavage. When seen by reflected light, the grains are usually pitted and covered with small grooves. The fragments of quartz are seldom quite pure and are generally made cloudy or even opaque by numerous enclosures (p. 171).

Quartz has a vitreous lustre, a conchoidal fracture, and a hardness of 7 according to Mohs' scale. Its specific gravity is about 2·65, its index of refraction 1·553, and its birefringence only 0·009.

Other forms of quartz may also sometimes occur in sands. The chief of these are *amethyst, rose quartz, milky quartz, smoky quartz*, and *aventurine*.

Quartz forms the main constituent of most sands, especially those derived from granite, gneiss, mica-schist, or sandstone, which consist almost entirely of quartz associated with a small amount of mica, felspar, magnetite, rutile, zircon, garnet, and tourmaline.

Tridymite was first discovered by G. von Rath in trachyte and other volcanic rocks, in which it occurs in hexagonal plates forming trins. Schuster and von Lasaulx have shown that tridymite crystals are pseudo-hexagons, being formed by three separate orthorhombic portions giving rise to the appearance of trins. Tridymite occurs almost wholly in sands derived from the disintegration of volcanic rocks such as trachytes and andesites. A fibrous form of tridymite containing 7 per cent of water is known as *Lussatite*. It has a specific gravity of 2·28 and a refractive index of 1·477.

Cristobalite was also discovered by G. von Rath in the same rocks in which tridymite was found, and has also been observed, according to A. F. Rogers, in minute spherical aggregates in spherulitic obsidian. It is a rare mineral, and is always associated with tridymite, being seldom found in sands. It belongs to the quadratic system, though trins are common and cause the crystals to appear pseudo-cubic. It has a specific gravity of 2·32 and a refractive index of 1·484.

The identification of the various crystalline forms of silica is difficult and requires the use of a special form of microscope and considerable manipulative skill. Cristobalite and tridymite are distinguished from each other and from quartz by means of their crystalline structure, refractive indices, and specific gravities, though the latter is only applicable to a limited extent. Quartz is found in irregular grains, whilst tridymite forms needle-shaped prisms. The test may not apply in sands which have been much transported, as the grains may be altered in shape by attrition. When examined by polarised light, quartz may be discriminated from tridymite and cristobalite on account of its higher birefringence. Tridymite and cristobalite cannot, however, be separated in this way, as the difference between them is too slight.

It is also possible to distinguish quartz from tridymite and cristobalite by immersing the powder in a liquid of specific gravity 2·40 (a mixture of bromoform and benzine being suitable), when the quartz will sink to the bottom whilst the other minerals remain suspended in the liquid.

The most satisfactory manner of discriminating between the three forms of crystalline silica is by their refractive indices. In the method, suggested by A. B. Dick and largely used by the author, a little of the material to be examined is immersed in an oil having a refractive index about the same as the sample, and the glass slip containing it is placed on the stage of a microscope and is illuminated by the use of a dark-ground illuminator, a yellow monochromatic light being used. Fringes will then be seen round the fragments of the sample, and if the liquid and the sample have the same refractive index, the fringes will have a deep ultramarine tint, whilst if the liquid has a higher refractive index the fringes will be paler and brighter or even white. If, however, the liquid has a lower refractive index than the sample, red or orange fringes are produced, these also becoming paler and brighter. Mercury-potassium iodide solution is very satisfactory for use in this test. For a yellow sodium light this solution should have a refractive index of 1·477, which is the refractive index of tridymite, so that cristobalite, which has a refractive index of 1·484, can readily be distinguished in this liquid, the test being so delicate that, if the solution is properly prepared, error is practically impossible.

Cellular Silica occurs in sands in the form of *kieselguhr*, *tripoli*, and *randanite* (see pp. 96 and 165) and also as *sponge spicules*. In most cases such cellular silica occurs as large beds, this form being the predominating constituent. It seldom occurs as a minor constituent of sand beds, though at Chipstead traces of siliceous sponges do occur.

Although silica is the principal constituent of most sands, all other minerals cannot be regarded as impurities, as, in some cases, they have a very beneficial action on the sand and may even be the principal constituent, silica being then regarded as an impurity.

The constituents of sands, apart from free silica, may be classified as follows:

(*a*) Silicates.
(*b*) Alumino-silicates.
(*c*) Iron compounds.
(*d*) Calcium compounds.
(*e*) Barium compounds.
(*f*) Aluminium compounds.
(*g*) Strontium compounds.
(*h*) Tantalum compounds.
(*i*) Titanium compounds.
(*j*) Thorium compounds.
(*k*) Tungsten compounds.
(*l*) Chromium compounds.
(*m*) Tin compounds.
(*n*) Zirconium compounds.
(*o*) Manganese compounds.
(*p*) Phosphorus compounds
(*q*) Metallic elements.
(*r*) Non-metallic elements.
(*s*) Rock fragments.
(*t*) Shells.
(*u*) Carbonaceous matter.

SILICATES

The commonest silicates occurring in sands belong to the groups named pyroxenes and amphiboles. The principal *pyroxenes* are as follows:

Enstatite is a magnesium silicate occurring in stout prismatic crystals belonging to the orthorhombic system, either colourless or of a grey, green, brown, or yellow colour, and having a hardness of 5·5 and a specific gravity of 3·1-3·3. It is derived from intermediate and basic igneous rocks such as andesites, dolerites, and peridotites. Owing to its being soft and readily decomposable it is only found in more recent deposits, such as shore sands.

Hypersthene is a silicate of iron and magnesium occurring in prismatic (orthorhombic) crystals of a brownish-green, greyish, greenish-black, brown, and sometimes nearly black colour. It has a hardness of 5·6 and a specific gravity of 3·5. It is derived from basic igneous rocks such as diorites, and occurs also in pyroxene granulites, etc. Hypersthene is a very common constituent of sands, especially those derived directly from igneous rocks.

Augite is a silicate of calcium, magnesium, iron, and aluminium occurring in monoclinic crystals of a black or greenish-black colour, with a hardness of 5-6 and a specific gravity between 3·2 and 3·5. It is derived from basic, igneous rocks, including andesites, basalts, diorites, gabbro, etc. Augite is also a common constituent of sands, especially those derived directly by the denudation of igneous rocks. Other pyroxenes which may occur in sands include *bronzite*, *diopside*, *diallage*, *aegerine*, and *wollastonite*.

The following are the principal *amphiboles* likely to occur in sands:

Hornblende consists of a silicate of calcium, magnesium, and iron, though silicates of aluminium, sodium, and potassium may be present. It forms black or greenish monoclinic crystals having a hardness of 5-6 and a specific gravity of 3·0-3·47. It is derived chiefly from acid and intermediate rocks such as granites, syenites, diorites, etc., and occurs largely in gneisses and schists, sometimes forming the bulk of the rock. Hornblende is common in rocks produced by the disintegration of igneous rocks. If present in sufficient quantities, it may give the sand a dark colour which is accentuated when it is heated.

Hornblende acts as a flux in the same way as other sodium and potassium compounds, and reduces the refractoriness of the sand in which it occurs.

Glaucophane is a silicate of sodium, aluminium, iron, and magnesium, of a bluish colour, having a hardness of 6-6·5 and a specific gravity of 3·0-3·1. It is derived chiefly from schists, where it occurs as a product of metamorphism. Glaucophane occurs in some shore sands, as at Île de Groix, Brittany, and in other localities.

Other amphiboles, which are less frequently found, include *anthophyllite*, *tremolite*, and *actinolite*.

Amphiboles do not occur to any great extent in the older sands, where they are usually altered to chlorite and other secondary products. They are, however, abundant in the Drift of Suffolk and in the Bunter beds of the Midlands. They also occur to some extent in the Bagshot beds, the Reading beds, the Thanet sand, the Wealden beds, and the Bunter beds of Ireland.

Amongst the other silicates which may occur in sands are the following:

Olivine forms a group of minerals consisting of a silicate of magnesium and iron of variable composition forming green, brownish, or blackish prismatic crystals (orthorhombic), having a hardness of 6-7 and a specific gravity of 3·0-4·2. It is principally derived from basic igneous rocks in which it is sometimes the predominating constituent. It is, however, readily decomposed, and so does not occur widely in sand deposits, because, in those which have been subjected to much transportation or weathering, the more easily decomposable minerals have been removed. Olivine sometimes occurs in recent sands, such as those composing the dunes of Holland, where they have been noted by Retgers. It is also found in desert sands, such as the Sahara, where it has not been exposed to the same decomposing agencies as marine sands and others formed by aqueous action. On the coast of Oahu in the Hawaiian Islands, a sand occurs consisting almost entirely of olivine and magnetite. It has been produced by the destruction of a basaltic lava, resulting in rounded angular grains of the above-mentioned minerals, the smaller grains being more angular than the larger ones.

Serpentine is a hydrated magnesium silicate which occurs as green, yellow, red, brown, or almost black monoclinic crystals, frequently spotted and veined with various colours. It is very soft, having a hardness of only 3-4 and a specific gravity of 2·5-2·6. It is derived from the weathering of olivine, pyroxene, and amphibole rocks. It is easily decomposed and does not occur to any great extent in sands. It sometimes occurs as a result of the decomposition of olivine.

Glauconite is an amorphous, granular, or earthy material consisting of a hydrated alumino-silicate of magnesium, and calcium. It varies in colour from yellowish-green to greyish-brown or blackish-green. It is very soft and has a hardness of only about 2 and a specific gravity of 2·2-2·4.

Glauconite is of very variable composition. It contains 45-48 per cent of silica, 3-10 per cent of alumina, 0-22 per cent of ferric oxide, 3-22 per cent of ferrous oxide, 0-6 per cent of magnesia, 0-2·5 per cent of lime, 4·5-9 per cent of potash, and 5·5-14·7 per cent of water.

Glauconite grains are very frequently found in internal casts of foraminiferae or other marine organisms, the mineral having

segregated in the interior of these shells and so taken their sh
It is also found coating these organisms.

Glauconite is almost entirely confined to marine deposits, i which it appears to be formed, according to Murray and Philippi, by the action of marine bacteria. It is very common in shallow water sediments, though it also occurs abundantly in moderately deep water. It is in all probability derived from the decomposition of potash felspars and potash micas. Though it occurs to a limited extent in many formations from the Cambrian beds upwards, it is most abundant in the Greensand beds and in the green muds of Agulhas Bank, South Africa. It is most abundant in the Upper and Lower Greensands of England, and in the north-east of Ireland it occurs in sandy beds as recent as the Lower and Middle Chalk. It is generally associated with phosphatic nodules. It also occurs to some extent in the Bagshot sands, Blackheath beds, Reading beds, Thanet sand, Wealden beds, and the Inferior Oolite.

Glauconite acts as a flux on account of the potassium it contains and reduces the refractoriness of the sand. For this reason, sands containing glauconite cannot be used for refractory purposes, but the potash they contain may be sufficient to render them valuable as fertilisers. The iron content of glauconite causes it to prevent the sands in which it occurs from being used for such purposes as glass-making.

Various anhydrous aluminium silicates are found in sands, the following being the chief:

Andalusite ($Al_2O_3 . SiO_2$) occurs as grey or reddish orthorhombic crystals, having a hardness of about 7·5 and a specific gravity of 3·1-3·3. It is chiefly derived from metamorphic clay rocks, but may be also derived from some granites.

Andalusite is not a very stable mineral and is readily decomposed, so that it does not occur to any great extent in the older sands. In Tertiary and Recent beds it is of more frequent occurrence. Perfect crystals of andalusite have been found, according to Davies, in the Bagshot sands of Brentwood, the Woolwich and Reading beds of Plumstead and Northwood, the Thanet sand at Crayford, the Folkestone beds of Dunton Green, Limpsfield, and Reigate, and the Wealden ironsands of Shotover Hill. It also occurs in the shore sands of Brittany.

When heated, andalusite is converted first into kyanite and then into sillimanite, the last reaction occurring, according to Vernadsky, at 1380° C.

Kyanite has the same chemical composition as andalusite, but forms triclinic crystals of a bluish-grey, green, and sometimes blackish colour, with a hardness from 4-7 and a specific gravity from 3·6-3·7. It is derived principally from gneiss, schists, and other metamorphic rocks.

Kyanite is a very stable mineral and is not readily decomposed, so that it is a very common constituent of sands of Cretaceous and more recent ages.

Sillimanite is also an aluminium silicate occurring as brown, grey, or green orthorhombic crystals, with a hardness of 6-7 and a specific gravity of 3·23. It is derived from felspathic gneisses, schists, etc.

Sillimanite is of somewhat rare occurrence and is not found to any great extent in British sands.

Topaz is a somewhat rare aluminium silicate containing fluorine, which occurs as white, yellow, grey, blue, or pink grains belonging to the orthorhombic system. It has a hardness of 8 and a specific gravity of 3·56. It is derived from many igneous rocks, including granites, rhyolites, etc., and is found chiefly in gem sands, especially in Brazil.

Staurolite is a silicate of iron and aluminium, occurring as reddish, brownish, or blackish orthorhombic crystals, having a hardness of 7-7·5 and a specific gravity of 3·7. It is derived from schists and gneisses, in which it occurs as a product of metamorphism. It is a very stable mineral and is a common constituent of sands of all ages, but is especially common in the Blackheath beds, the Thanet sand, the Lower Greensand, the Upper Estuarine sands, the Inferior Oolite, the Keuper Waterstones, and the Bunter beds.

Alumino-Silicates

There are many varieties of alumino-silicates which may occur as constituents of sands, the principal being the clays and allied minerals, including felspars and micas.

Clays are hydrous alumino-silicates which occur to a varying extent in association with sands. The number of different clays which may occur is very large and a detailed classification of them is practically impossible. It is generally agreed that the chief constituent is a hydrogen alumino-silicate corresponding to $H_4Al_2Si_2O_9$, and composed of about 46 per cent of silica, 39 per cent of alumina, and 14 per cent water, for which the name "clay substance" as originally proposed by Seger is convenient. Recent researches have indicated that a number of different alumino-silicates may form different kinds of clay, but for the purposes of the present volume they need not be differentiated. Clay substance never occurs in a perfectly pure state in association with sand, but contains various impurities, such as alkalies in the form of mica, felspar, etc., and iron compounds, the proportion of which varies considerably. Some clays may be almost pure white, whilst others may be a deep red on account of the proportion of iron compounds present. Carbonaceous matter may also occur and give the clay a dark colour.

The nature and properties of clays are subjects far too extensive to be dealt with in detail in the present volume, and readers requiring further information should refer to the author's book on *British Clays, Shales, and Sands* (Griffin).

The proportion of clay in a sand depends on the mode of

formation. Where a rock has been disintegrated into clay and sand, as in the case of china clay rock, and has not been transported, almost the whole of the clay remains in the sand. Where sands have been removed from place to place by wind, water, etc., the clay is generally separated from the sand (at least to a large extent) on account of its finer grains and greater suspensibility in water. River sands are usually fairly free from clay; estuarine, lacustrine, and marine sands may contain large proportions of clay.

The effect of clay upon sand is noticeable in various ways:

1. On account of its binding power, sands containing clay are more or less coherent. The extent to which they are bound together depends on the proportion of clay present. This property is valuable for foundry-work, etc., where sands require to be coherent to form a mould, but for building purposes, glass-making, etc., where a loose incoherent sand is required, clay is not desirable.

2. Clays introduce alumina into the sand; this may or may not be desirable. Thus, for making some kinds of glass, alumina is valuable, as it increases the strength of the glass. In other glasses, particularly optical glass, it is undesirable (see Vol. II., Chapter XII.). In making carborundum, alumina is undesirable (see Vol. II., Chapter X.). Thus, the desirability or otherwise of clay depends on the purpose for which the sand is to be used.

3. Clay tends to introduce impurities such as alkalies, iron compounds, etc., into the sand. This may not be important for some purposes, but in others, such as for glass-making, chemical manufacture, etc., it is very detrimental and clayey sands must be avoided.

4. On account of the smallness of the grains of clay, these tend to fill up the interstices between the larger grains of sand, so producing a less porous mass. This is not harmful in many cases, but where a porous or permeable sand is required, or where an excess of fine particles is undesirable, as in concrete sands, glass sands, filtration sands, etc., the presence of clay is deleterious.

The effect of clay in sands used for special purposes is dealt with in greater detail in Vol. II.

Several minerals similar to clay may occur in sands, though usually they are present only in minute quantities. Among these:

Halloysite ($Al_2O_3 . 2SiO_2 . 3H_2O$) consists of soft bluish-white, green, or grey crystals of amorphous material having a specific gravity of 1·9-2·1.

Collyrite ($Al_2O_3 . SiO_2 . 9H_2O$) consists of a dirty white powdery material.

Allophane ($Al_2O_3 . SiO_2 . 5H_2O$) is a blue or bluish-green mineral and is harder than collyrite.

Nacrite consists of white flaky rhombic crystals.

Lithomarge consists of minute white or cream-coloured rhombic plates of variable composition.

Pyrophyllite ($Al_2O_3 . 4SiO_2 . nH_2O$) consists of rhombic crystals.

Montmorillonite ($Al_2O_3 . 4SiO_2 . H_2O$) is soft and of a pinkish colour.

Kaolin or *China Clay* is a hydrated aluminium silicate or alumino-silicate ($Al_2O_3 . 2SiO_2 . 2H_2O$) which may occur as white, grey, or yellowish monoclinic crystals of *kaolinite*, having a hardness of 2·0-2·5 and a specific gravity of 2·6, or as an apparently[1] amorphous material, having the same chemical composition, but devoid of crystalline structure. It is produced by the weathering of granite (p. 16), and occurs in sands in varying proportions according to the amount of transportation to which they have been subjected.

Felspar is a term applied to a group of alumino-silicates containing one or more basic oxides, the various members being usually designated by the principal base present, such as potash felspar. The principal felspars are:

Orthoclase, which is a potash felspar occurring as white, grey, or pinkish monoclinic crystals, having a hardness of 6 and a specific gravity of 2·57. It is derived chiefly from acid igneous rocks, such as granites, syenites, etc.

Microcline is a potash felspar occurring as greyish, greenish, or pinkish triclinic crystals, with a hardness of 6-6·5 and a specific gravity of 2·55. Like orthoclase, it is derived from acid igneous rocks, particularly granites.

Albite-anorthite felspars form a series grading from a pure sodium felspar (albite) to a pure calcium felspar (anorthite) with various intermediate mixtures, designated under the general term plagioclase felspar. They are usually white, grey, or greenish triclinic crystals, with sometimes a pinkish tinge, having a hardness from 5-6·5 and a specific gravity of 2·6-2·75. They are derived from all types of igneous rocks, the calcium felspars being commoner in basic rocks, whilst the sodium felspars are usually found in acid rocks.

Felspar is a common constituent of sands, but is frequently corroded or clouded, as it is attacked to some extent by carbonated water, which results in the loss of some of the alkali and the forming of other alumino-silicates and free quartz. Fresh felspar is more common in deposits of terrestrial origin, such as wind-blown sands, in which the grains of felspar are often quite transparent.

The gradual disappearance of felspar in sands is well shown by the following figures, due to Dr. Mackie, of the percentages of felspar in the sands of the river Findhorn (Scotland) from its source to the sea:

At Dulsie Bridge	42 per cent.
At Logie Bridges . . .	31 ,,
Between Forres and the sea	24 ,,

A high percentage of felspar indicates that the sand has under-

[1] Sir W. H. Bragg has found, from an examination of its X-ray spectrum, that china clay is crystalline though the crystals are too small to be observed under the microscope.

gone little transportation by rivers and has been subject to very little action by water.

Table XXV., due to Mackie, shows the percentage of felspar in sands derived from different sources.

TABLE XXV.—FELSPAR IN SANDS

Source of Sand.	Fresh Felspar.	Altered Felspar.
	Per cent.	Per cent.
Boulder clay	86	14
Boulder clay	83	17
East Egyptian desert	72	28
Nile delta	high	low
River Spey	19	81
Lower Old Red Sandstone (Caledonian)	20-30	70-80
Upper Old Red Sandstone (Caledonian)	30-40	60-70

The felspars are among the most fusible compounds of silica; this is due to their containing a large proportion of calcium, sodium, or potassium in combination with the alumina and silica. In the results of a chemical analysis, the sodium and potassium compounds are often expressed as *alkalies*, a term which is undesirable as it gives no indication of the respective proportions in which the sodium and potassium may occur.

On account of their fusibility, the action of felspars in sands is to reduce the refractoriness of the sand as a whole. Potash felspar fuses at a temperature of 1200° C., and the molten material flows rapidly through the interstices of the sand, so that as soon as a sufficient quantity of fused matter is produced the sand loses its resistance to heat. The action of potash, however, is in this respect slow compared with that of lime in similar compounds.

The effect of orthoclase felspar on quartz when mixtures of both are heated is shown in Table XXVI., due to R. Rieke.

TABLE XXVI.—FUSIBILITY OF ORTHOCLASE-QUARTZ MIXTURES

Orthoclase.	Quartz.	Fusing Point.
		° C.
100	..	1220
40	60	1265
33	67	1285
25	75	1292
14	86	1317

For refractory purposes, a sand containing grains of felspar is less objectionable than one containing flakes of mica, as the former are less rapid in their action, there being less surface to the grains in proportion to their bulk.

a term which includes a number of minerals consisting of silicates of aluminium, potassium, and hydrogen, . ⁄ith iron, magnesium, sodium, and lithium. Micas lise in the monoclinic system and may be divided into two ɔs: the muscovite micas and the biotite micas.

Muscovite consists of white, yellow, green, brown, or blackish akes having a hardness of 2-2·5 and a specific gravity of 2·85. It is derived principally from acid igneous rocks, especially granites. Muscovite may be observed in sands as white glistening flakes or frost-like particles, very small proportions of mica being readily recognisable in this way. This variety of mica is usually abundant in sands formed by aqueous action, though very curiously it is absent in desert sands, probably because the thin light flakes are easily earried away by wind and, consequently, are removed from the main deposit. In water, however, this separation does not take place to the same extent, so that the mica in water is not removed from the other minerals, but tends to accumulate in layers, as, in comparatively still water, the particles of quartz and mica are deposited at different rates owing to the fact that the mica grains, being thin and flat, are more buoyant than the more granular quartz grains.

Lepidolite resembles muscovite, but contains lithium and fluorine; it forms white, grey, lilac, or rose-red crystals, with a hardness of 2·5-4 and a specific gravity of 2·8-2·9. It is derived largely from metamorphic rocks, sueh as pegmatites.

Sericite is very similar to muscovite and is sometimes regarded as an aggregated form of museovite, though it is also thought to be alteration-product of felspar. It is especially common in Carboniferous and older rocks.

Biotite occurs as blaek or dark-green crystals of variable eomposition, with a hardness of 2·5-3 and a specific gravity of 2·7-3·1. It is derived from all kinds of igneous rocks and their volcanic equivalents, and also oecurs abundantly in metamorphic rocks.

Biotite mica occurs only rarely in sands, as it decomposes on weathering, forming chlorite and limonite, but it is found in some sands which have not been seriously affected by weathering. It occurs to some extent in the Reading beds, Thanet sand, Upper Greensand (it is absent from the Lower Greensand), the Bunter beds of the Midlands, the Lower Permian of Yorkshire, the Coal Measures of Northumberland, and the Millstone Grit of Yorkshire.

Phlogopite is similar to biotite, but is colourless, white, brown, or red in colour.

Mica in any of its forms reduces the refractoriness of sands in which it occurs, but its aetion is not usually appreciable much below a temperature of about 1200° C., and it is, like felspar, a comparatively slow flux. The effeet of mica on the refractoriness of silica is shown in Table XXVII., due to R. Rieke.

TABLE XXVII.—FUSIBILITY OF MICA-QUARTZ MIXTURES [1]

Quartz.	Mica.	Fusing Point.
Per cent.	Per cent.	° C.
100	..	1790
90	10	1710
80	20	1630
70	30	+1530
60	40	– 1530
50	50	– 1530
40	60	– 1530
30	70	1530-1580
20	80	1610
10	90	1410
..	100	1380

The iron content of mica is sometimes objectionable where a pure sand is required, as in glass-making, as the iron compounds on heating discolour the fused mass. Biotite mica is particularly objectionable in this respect, as, being dark, its effect is more pronounced.

Other alumino-silicates which may occur in sands include the following:

Tourmaline is a borosilicate of aluminium, which occurs generally as black or blue-black hexagonal crystals, with a hardness of 7-7·5 and a specific gravity of 2·98-3·2. It is derived partly from acid igneous rocks and also from metamorphic rocks such as schists, crystalline limestones, etc. Tourmaline is a very stable mineral and is a frequent constituent of sands of all ages.

Beryl is a silicate of beryllium and aluminium, occurring as pale green, blue, yellow, or white hexagonal crystals, with a hardness of 7·5-8 and a specific gravity of 2·7. It is derived from acid igneous rocks, metamorphic schists, and crystalline limestones. Beryl is found chiefly in placer deposits along with other gem stones and a large proportion of heavy minerals.

Chlorite is a term used to designate a number of hydrous alumino-silicates containing iron and magnesium, which form soft greenish hexagonal flakes with a hardness of about 1·5 and a specific gravity of 2·6-2·8. It is a metamorphic product derived from the alteration of biotite, hornblende, etc., and occurs largely in schists. Chlorite is a readily decomposable mineral and so does not occur to any great extent in sands, except as the result of the decomposition of other minerals. It has been found to some extent in the Inferior Oolite beds and in the Millstone Grit of Wales.

Epidote is a term used to designate a number of alumino-silicates containing iron, calcium, and hydrogen and sometimes manganese, cerium, etc. They are usually greenish or brownish

[1] The *plus* sign indicates that the fusing point is slightly above, and the *minus* sign that it is slightly below, the figure stated.

in colour and form monoclinic crystals, having a hardness of 6-7 and a specific gravity of 3·25-3·5. It is derived chiefly from gneiss and schists which have been formed from igneous rocks rich in lime. Some varieties may also be derived from granites.

Epidote is not found to any great extent in sands older than Tertiary age. It is abundant in the Drift of Suffolk and occurs to some extent in the Bagshot sands, Blackheath beds, Reading beds, Thanet sand, the Upper Greensand, and also in the Lower Permian beds of Yorkshire. It has also been found in the dune sands of Holland by Retgers. In some sands it occurs as the result of the decomposition of other minerals.

Zoisite is a variety of epidote derived from metamorphic rocks.

Cordierite is an alumino-silicate containing iron, magnesium, and water, which occurs as bluish, orthorhombic crystals having a hardness of 7-7·5 and a specific gravity of 2·6-2·7. It is derived chiefly from metamorphic gneisses, schists, etc., but it may also be derived from some igneous rocks, including basalts and granites. Owing to its readily decomposable nature it is not found to any great extent in the older sands, but occurs more frequently in Tertiary and Recent sands.

Garnet is a term used to designate a number of alumino-silicates, containing lime, magnesia, iron, manganese, and chromium, which occur in rhombohedral or trapezohedral crystals of various colours, including yellow, green, brown, red, and black. They have a hardness of 6·5-7·5 and a specific gravity of 3·5-4·2. The varieties of garnet are described on p. 111. Garnets are derived from various igneous rocks, including granite and syenite; they also occur in metamorphic schists, gneisses and crystalline limestones, and dolomites.

Garnet is a very stable mineral and is not easily decomposed, so that it is a common constituent of sands of all ages. It is particularly common in sands between the Jurassic and Pliocene periods.

Iron Compounds

No natural sands are entirely free from iron compounds, and even the most stringent attempts at purification do not succeed in completely removing all the iron present. The chief compounds of iron occurring in sands are the oxides, carbonates, and sulphides, and various complex minerals containing iron as an essential constituent, such as glauconite, ilmenite, etc. These compounds are derived from decomposed ferruginous rocks, either by direct admixture or by the compounds being dissolved by organic acids, the solution penetrating into the sand and being decomposed later.

In the analysis of a sand it is customary to report the iron compounds as though they were all present as the red oxide (Fe_2O_3), no distinction being made as to the forms in which the iron

is actually present; yet in many sands the proportion of fe oxide is quite small, the iron being present in other forms.

Iron compounds may occur in sand in three forms:

(*a*) As a thin film coating the grains of other minerals;
(*b*) In minute particles disseminated fairly uniformly through the sand;
(*c*) As larger particles scattered irregularly amongst the grains of other minerals.

Magnetite (Fe_3O_4) is a black oxide of iron which occurs in cubic crystals, with a hardness of 5·5-6·5 and a specific gravity of 4·9-5·2. It is highly magnetic and can usually be removed quite easily by means of a magnet. Magnetite is one of the commonest heavy minerals in sands and is found in practically all detrital sediments. In some cases, it is partially oxidised to limonite.

In some sands the magnetite has been concentrated by water action, forming large deposits containing but little of other minerals, as, for example, the black sands of the St. Lawrence river, Canada (p. 122).

Haematite (Fe_2O_3) is a red oxide of iron occurring as steel-grey, iron-black, or reddish hexagonal crystals, or as amorphous grains having a hardness of 5·5-6·5 and a specific gravity of 4·5-5·3. It is abundant in the Lower Permian beds of Yorkshire and in some Northampton sands.

Limonite is a hydrated iron oxide, consisting of yellow or brownish amorphous grains, having a hardness of 5-5·5 and a specific gravity of 3·6-4·0. It is formed by the weathering of iron-bearing minerals and also by deposition from solutions of iron in water. Bog iron-ore and lake iron-ore are limonite beds. Brown iron-ores are worked in Northamptonshire, the north of Spain, Luxembourg, and Western Germany.

So far as sands are concerned, limonite is chiefly of interest as being the form in which iron is usually present. It is soluble in hydrochloric acid and is volatilised by heating with salt to a bright red heat, but these methods are too costly to enable them to be applied to the elimination of limonite from most sands. Limonite is common in the Thanet sand, the Upper Greensand, and the Kellaways beds. Limonite may also occur as *ochre*, this material sometimes forming the bulk of the material, as in the Lower Greensand of Shotover Hill, Oxford, and also as *umber*, which is a brownish ferruginous earth containing silica, iron oxide, and manganese oxide, the latter sometimes being the predominating constituent.

Other iron compounds which occur only rarely in sand deposits include *pyrites*, *marcasite*, *pyrrhotine*, *chalybite*, and *vivianite*.

Many other substances containing iron in varying proportions occur in sands, including *hornblende*, *hypersthene*, *augite*, *glaucophane*, *olivine*, *glauconite*, etc.; they have the same effect as richer iron compounds, if they are present in sufficient quantities. Usually, however, only very small proportions are present.

The chief effect of iron compounds in sands is to reduce their refractoriness and to cause them to be brownish in colour. The intensity of the colour produced by iron is not a reliable indication of the amount present, as much depends on the fineness of the sand and on the nature of the iron compounds contained therein, whilst the presence of other substances may partially or wholly mask the colour of the iron compounds. When the iron is disseminated uniformly through the sand either in small grains or as a film over the other particles, the colour is much more pronounced than when larger grains are scattered irregularly through the mass. These latter can be separated much more readily than the smaller grains.

Where iron compounds are present in the ferrous state, the colour of the sand may not be greatly altered, as the ferrous compounds are greenish rather than brown, and are not so conspicuous, but on heating the sand to redness in a current of air the ferrous compounds are oxidised to ferric compounds, and produce the characteristic brown colour.

Ferrous compounds and magnetite are most [illegible] in sands, as, when heated, they combine readily with [illegible] any alumino-silicates which may be present, forming fusible compounds which reduce the refractoriness of the sand.

Red ferric oxide is almost infusible if heated in an oxidising atmosphere, so that its presence in a refractory sand is not so serious as the presence of ferrous compounds and magnetite, but if it is heated in a reducing atmosphere, it may be reduced either to magnetite or ferrous oxide, and so may be equally as harmful as when these compounds are present naturally in the sand.

Generally speaking, if iron compounds in sands are heated exclusively under oxidising conditions, their effect on the fusibility of a sand will be very slight. If, on the contrary, a reducing medium is present, the iron compounds will be correspondingly reduced and will act as powerful fluxes.

Calcium Compounds

Calcium compounds occur in sands in various forms, the following being the chief:

Calcite is a carbonate of calcium which occurs as white, grey, or tinted hexagonal crystals, having a hardness of 3 and a specific gravity of 2·71. It may occur in crystalline form or it may form a tufa or calcareous sinter.

Calcite (often with dolomite) frequently occurs in sands derived from the Glacial Drift. It has also been found in some dune sands.

Aragonite has the same chemical composition as calcite, but crystallises in the orthorhombic system, forming white, grey, yellowish-green, or violet crystals, having a hardness of 3·5-4 and

a specific gravity of 2·94. Aragonite forms the greater proportion of many coral and shell sands.

Gypsum is a hydrous calcium sulphate, occurring in colourless white, grey, yellowish, or reddish grains of monoclinic crystals, having a hardness of 1·5-2 and a specific gravity of 2·3. *Anhydrite* is an anhydrous form of gypsum occurring as white, grey, bluish, or reddish orthorhombic crystals.

Fluorspar is a calcium fluoride; it occurs in colourless, white, green, purple, yellow, or blue cubic crystals, with a hardness of 4 and a specific gravity of 3·0-3·25. It is derived chiefly from mineral veins, in which it occurs as a gangue mineral.

Felspars and **micas**, as well as other alumino-silicates, may also contain lime compounds, and although the proportion present may be less than 15-20 per cent, the effect of this proportion may be serious, so that these minerals should also be considered to some extent as lime compounds, as their principal effect on sands depends on the amount of this particular flux which they contain.

Calcium compounds frequently occur in glacial sands as a result of the breaking up and powdering of limestone blocks by the action of ice.

When the calcium carbonate has been brought into the sands by percolating water, it may form a film or coating over the quartz and other grains present. This may be distinguished by the fact that it effervesces when treated with hydrochloric acid.

The effects of lime compounds on sands are very varied:

1. If the sand is to be used in the manufacture of bricks which are burned in a kiln, the lime compounds may be converted into quicklime during the firing, and when the goods are later exposed to moisture, they will probably crack, or at any rate, the lime will slake and may fall out ("blow"), leaving a cavity corresponding to the size of the mass of free lime. For this reason, the presence of lime compounds in such sands is undesirable, and if present at all, must be in such a fine state of division that they will not do any harm, should they be converted into quicklime and afterwards slaked. Lime compounds may be removed from sand by washing, unless the particles are very small.

2. Lime compounds react with silica at very low temperatures, forming calcium orthosilicate or calcium metasilicate, the latter being generally formed in the presence of a large excess of silica. According to J. W. Cobb, the reactions take place below the melting points of both lime and silica and may be completed at almost any temperature between 800° and 1400° C. Table XXVIII., due to R. Rieke, shows the effect of lime on the refractoriness of silica in the form of fine quartz sand.

When free alumina is present in the sand, the lime and the alumina unite at a temperature of 850°-900° C. and more rapidly at 1100°-1300° C., forming a calcium aluminate. Ternary compounds or alumino-silicates may also be formed by the interaction of lime, silica, and alumina.

TABLE XXVIII.—FUSIBILITY OF LIME-SILICA MIXTURES [1]

Lime.	Silica.	Refractoriness.
		° C.
..	6	1790
1	6	1710-1730
1	5	1710
1	4	+1690
1	3	1650
2	5	1530-1580
1	2	1435
5	9	1410
10	17	1410
5	8	1410-1435
2	3	1435
5	7	1435-1460
10	13	1460
4	5	1460-1480
5	6	1480
1	1	1520
10	9	+1480
5	4	1435-1460
10	7	+1410
5	3	-1460
2	1	1650

Table XXIX., due to J. W. Cobb, shows the temperatures at which lime acts on silica and the various compounds formed.

TABLE XXIX.—REACTION TEMPERATURES OF LIME-SILICA MIXTURES

	Commencement of Reaction.	Completion of Reaction.	Product.
	° C.	° C.	
1 part calcium carbonate and 1 part silica	800	1400	$CaO . SiO_2$
1 part calcium carbonate and 10 parts silica	800	1250	$CaO . SiO_2$
1 part calcium sulphate and 10 parts silica	1000-1200	1300	$CaO . SiO_2$
3 parts calcium carbonate and 1 part silica	800	1250	$2CaO . SiO_2$

The action of lime may be altered by the presence of other fluxes in the sand. When alkalies are present simultaneously with lime (as is usually the case), they reduce the temperature at which interaction occurs, as sodium and potassium silicates and alumino-silicates are formed at a lower temperature, and fuse

[1] See footnote on p. 187.

more readily, than the corresponding lime compounds. Moreover, any fused matter which may be present acts as a solvent of lime, silica, and alumina, and thereby facilitates their interaction.

When iron oxide is present, calcium metaferrate ($CaO . Fe_2O_3$, melting at 1205° C.) or calcium orthoferrate ($2CaO . Fe_2O_3$, melting at 1400° C.) may be formed. According to R. B. Sosman and H. F. Merwin, both these substances dissociate at their melting points, the latter giving black crystals with a yellowish-brown tinge, and the former yielding long black needle-shaped crystals.

The extent to which these reactions will occur depends chiefly on the relative quantities of each of the constituents present, the size of the particles, the temperature to which the mixture is heated, and the duration of the heating.

Lime compounds are amongst the most powerful fluxes, and a small percentage of minerals containing lime may reduce the [illegible]e sand very considerably. The effect of lime compounds in this way depends on the size of the grains and the intimacy with which they are associated with the other constituents of the sand. Thus, the very minute particles uniformly disseminated through the sand are much more active in their action than larger irregularly disposed particles.

The form in which the lime is present also affects the activity of the reactions. In the form of carbonate, the action is very rapid, as the carbonate is decomposed at a temperature of about 700° C., forming free lime which attacks the silica and silicates present very rapidly. Calcium sulphate does not dissociate below a temperature of 1200° C., but above this temperature its action is exactly like lime or calcium carbonate. In the form of felspar and other calcium-bearing alumino-silicates the action of the lime is also retarded to some extent, the refractoriness not being reduced so greatly as with compounds which produce free lime.

3. Soluble calcium compounds may produce a scum on any articles made from the sand, unless such compounds are changed into some insoluble form during the course of manufacture.

Barium Compounds

Barium compounds occur in sands, the only one of importance being **Barytes,** which occurs as colourless or white orthorhombic crystals, sometimes tinged with yellow, red, brown, or blue, having a hardness of 2·5-3·5 and a specific gravity of 4·5. It is derived chiefly from mineral veins in which it occurs as a gangue. Barium compounds in sands act in almost exactly the same way as calcium compounds, so that their action need not be described separately. Barium silicate melts, according to G. Stein, at 1368·5° C., and according to R. C. Wallace, at 1490° C.; the latter figure probably relates to the disilicate.

Magnesium Compounds

Magnesium compounds may occur in sands in any of the following forms:

Magnesite occurs as white, grey, yellow, or brown grains, sometimes in hexagonal crystals, having a hardness of 3·5-4·5 and a specific gravity of 2·8-3 or more. It is produced by the alteration of rocks rich in magnesium silicates, chiefly vein rocks.

Dolomite is a carbonate of calcium and magnesium which occurs as white or tinted hexagonal crystals, having a hardness of 3·5-4 and a specific gravity of 2·8-2·9. It occurs rarely in recent sands such as those in the Drift of Suffolk.

Spinel, see below.

Cordierite, see p. 188.

The effect of magnesium compounds on sands is to reduce their refractoriness, but, unlike lime compounds, the rate of fusion is comparatively slow, and the compounds formed are very viscous in the molten state, so that where the sand is used in the manufacture of articles which are afterwards burned in a kiln, the vitrification range is much larger and there is less danger of the goods losing their shape than when lime compounds are present.

Aluminium Compounds

The aluminium in sands chiefly occurs in the felspars, micas, pyroxene, amphibole, clay, and other alumino-silicates, and other minerals present as impurities, but a small proportion may occur as free alumina. The principal forms of free alumina which may occur are as follow:

Corundum consists of grey, green, reddish, or yellow hexagonal crystals, having a hardness of 9 and a specific gravity of 3·9-4·1. It is derived chiefly from veins and segregations of igneous rocks.

Bauxite, Laterite, and **Diaspore** are hydrous forms of alumina which occur very occasionally in sands. Bauxite is an amorphous, earthy, or granular material of dirty white or brownish colour. Laterite is an impure form containing much iron oxide. Diaspore forms white orthorhombic crystals, with a hardness of about 7 and a specific gravity of 3·5.

The effect of alumina on sands varies according to the state in which it is present and with what it occurs. Alumina reduces the refractoriness of sands when small proportions are present, but larger proportions increase the refractoriness. Table XXX., due to Seger, Hecht, and Simonis, shows the effect of alumina on the refractoriness of silica.

Spinel is the term used to designate a group of minerals of varying composition, but consisting essentially of magnesium aluminate, though iron, manganese, and chromium may replace some of the magnesia. They occur as red, brown, black, or sometimes green or blue cubic crystals, having a hardness of 8 and a

TABLE XXX.—FUSIBILITY OF ALUMINA-SILICA MIXTURES

Silica.	Alumina.	Refractoriness.
		° C.
100·0	..	1770
93·5	6·5	1710
91·6	8·4	1670
89·9	10·1	−1610
87·2	12·8	+1610
85·2	14·5	1630
82·5	17·5	1650
78·0	22·0	1670
74·7	25·3	1690
70·3	29·7	1710
63·9	36·1	1730
59·6	40·4	1750
54·2	45·8	1770
49·5	50·5	1790
44·0	56·0	1825
37·1	62·9	1850
28·1	71·9	1880
18·0	82·0	1920
7·1	92·9	1960
..	100·0	2000

A *minus* sign indicates a temperature slightly below that shown.
A *plus* sign indicates a temperature slightly above that shown.

specific gravity of 3·5-3·6. They are derived chiefly from basic igneous rocks and from metamorphic gneisses, serpentines, and crystalline limestones.

Chrysoberyl is a beryllium aluminate derived from granite, gneiss, and mica-schist, which occurs to a limited extent in sands as green orthorhombic crystals, having a hardness of 8·5 and a specific gravity of 3·5-3·8.

STRONTIUM COMPOUNDS

Strontium compounds are very rare in sands, the only one of any importance being **Celestine,** which is a sulphate of strontium occurring as white orthorhombic crystals, having a hardness of 3-3·5 and a specific gravity of 3·96.

TANTALUM COMPOUNDS

Tantalum compounds are also rare in sands, the chief one being **Tantalite,**—a niobate and tantalate of iron and manganese which occurs as black, grey, or brown orthorhombic crystals, having a hardness of 6 and a specific gravity of 5·3-7·3.

Titanium Compounds

Titanium compounds occur in sands in the following forms :

Rutile is a titanium oxide occurring as reddish-brown, yellowish, or black tetragonal crystals having a hardness of 6-6·5 and a specific gravity of 4·2. It is derived chiefly from acid igneous rocks and metamorphic rocks, though it may also occur as an alteration product of other titanium minerals. Rutile is one of the commonest detrital minerals in sands, on account of its great stability. It is almost indestructible, and may be passed on from one deposit to another with practically no change. In some cases rutile is concentrated by water action forming large deposits containing but little quartzose material (p. 164).

Brookite is a titanium oxide occurring as brown, reddish, or blackish orthorhombic crystals, with a hardness of 5·5-6 and a specific gravity of 4. It is also an alteration product, derived especially from dolerites. Brookite is less widely distributed than rutile, but is very common in the Coal Measures of Durham and the Millstone Grit of Yorkshire.

Anatase is also a titanium oxide which occurs as slender tetragonal pyramids of a brown, blue, or black colour, having a hardness of 5·5-6 and a specific gravity of 3·82-3·95. It is an alteration product from other titanium minerals and is principally derived from granites, dolerite, schists, etc. Anatase, like brookite, is also of more local occurrence than rutile. It is abundant in the Keuper Waterstones, and occurs to some extent in the Drift of Suffolk, the Wealden beds, the Inferior Oolite of Northamptonshire, the Bunter beds of the Midlands, and in Ireland, the Lower Permian of Yorkshire, the Coal Measures of Northumberland, the Millstone Grit of Yorkshire and Scotland, the Carboniferous Limestone, and the pocket sands of Derbyshire and North Wales.

Ilmenite is an oxide of iron and titanium occurring as black hexagonal crystals, having a hardness of 5-6 and a specific gravity of 4·5-5·0. It is derived from basic igneous rocks, especially diorites, and also from the disintegration of intrusive veins. It is one of the commonest heavy minerals, and is found in practically all detrital sediments. In some cases it may be partly converted into leucoxene and anatase. Ilmenite is sometimes concentrated into large placer deposits containing few other minerals.

Sphene or Titanite is a titanate and silicate of calcium which occurs as brown, green, grey, yellow, or black monoclinic crystals, having a hardness of 5-5·5 and a specific gravity of 3·54. It is derived chiefly from acid igneous rocks such as granite, syenite, etc., and also from metamorphic rocks, rich in calcium.

Leucoxene is a variety of sphene produced by the alteration of ilmenite and other titanium-bearing minerals. It is found in most sands and deposits where other titaniferous minerals occur, and is especially frequent in Carboniferous rocks.

Titanium compounds act as powerful fluxes, and, if present in

quantities exceeding 2 per cent, they greatly reduce the refractoriness of the sand. The effect of titanium oxide on the refractoriness of silica is, as shown in Table XXXI., due to R. Rieke.

TABLE XXXI.—FUSIBILITY OF TITANIUM OXIDE-SILICA MIXTURES

Silica.	Titanium Oxide.	Refractoriness.
		° C.
100	..	1790
90	10	1730-1750
80	20	1650-1670
70	30	1580
60	40 (Eutectic)	1530
50	50	1610
40	60	1670
30	70	1650
20	80	1650-1670
10	90	1650
..	100	1610

The effect of titanium oxide as a flux on alumina is even more marked than on silica, as is shown in Table XXXII., also due to R. Rieke.

TABLE XXXII.—FUSIBILITY OF TITANIUM OXIDE-ALUMINA MIXTURES

Alumina.	Titanium Oxide.	Refractoriness.
		° C.
100	..	2000
80	20	1825
70	30	1770
60	40	1730
50	50	1730
40	60	1730-1750
30	70	1690
20	80	1650
10	90	1630
..	100	1610

THORIUM, CERIUM, AND YTTRIUM COMPOUNDS

The only important thorium compound occurring in sands is **Monazite,** which is a phosphate of cerium metals and thorium silicate, and occurs as pale yellow or reddish-brown monoclinic crystals, having a hardness of 5·5 and a specific gravity of 5·0. It is derived from granites and pegmatites.

Thorianite and **Thorite** are also sources of thorium, but they occur only rarely in sands.

Xenotine is a mineral similar to monazite, consisting of phosphates of the cerium and yttrium groups, together with silica, thoria,

zirconia, etc. It contains 8-11 per cent of ceria earths and 54-65 per cent of yttria earths, and occurs as brown to reddish-brown or yellow tetragonal crystals, with a hardness of 4-5 and a specific gravity of 4·45-4·56. It is frequently associated with zircon, especially in granitic rocks, and is abundant in the diamond sands of Brazil and in Scandinavia. In smaller proportions it occurs in other rocks, such as those of the Millstone Grit, and in some detrital sands.

Tungsten Compounds

Tungsten compounds occur in sands in varying quantities. The following are the principal varieties:

Wolframite is a tungstate of iron and manganese which occurs as brown or greyish-black monoclinic crystals, having a hardness of 5-5·5 and a specific gravity of 7·1-7·9. It is derived from pneumatolytic veins.

Scheelite is a tungstate of calcium which occurs rarely as yellowish or brownish tetragonal crystals, with a hardness of 4·5-5 and a specific gravity of 5·9-6·1. It is also derived from pneumatolytic veins.

Hubnerite is a tungstate of manganese which occurs very rarely in sands.

Chromium Compounds

There are various compounds containing chromium as a minor constituent in sands, but the only one which contains a large proportion is **Chromite,** which occurs as black or brownish-black cubic crystals, with a hardness of 5·5 and a specific gravity of 4·3-4·5. It is derived chiefly from ultra-basic rocks, peridotites, etc. It is very resistant to weathering, and is carried about in sands without any appreciable alteration.

Tin Compounds

Tin compounds occur in sands only as **Cassiterite**; it is found usually as black or brown tetragonal crystals, with a hardness of 6-7 and a specific gravity of 6·4-7·1. It is derived from granites and quartz veins as well as other acid igneous rocks. It is found in the sands of Cornwall and other tin-bearing districts, and has also been found, to some extent, in the pocket-sands of Derbyshire.

Zirconium Compounds

Zirconium compounds occur in sands principally as **Zircon** (zirconium silicate), which consists of colourless green or reddish-brown tetragonal crystals, having a hardness of 7·5 and a specific gravity of 4·7. It is derived from many types of igneous rock, especially acid ones, and also from crystalline limestones, gneisses, and schists.

Zircon is an extremely durable mineral, and may be repeatedly transported from one deposit to another without any material changes. Consequently, it is one of the commonest constituents

of sands, and is found in almost every deposit. In some cases it is concentrated by water action forming large deposits practically free from other minerals.

Manganese Compounds

Manganese oxides occasionally occur in some dark sands. They act as powerful fluxes and rapidly decrease the refractoriness of sands in which they occur. They also give the sands a brown colour, if present in sufficient quantity, which may be an objection to their presence. Manganese compounds may occur as a thin film over the quartz and other constituents of the sand, giving the whole bed a brown colour, which may be removed to some extent by washing.

Phosphorus Compounds

Phosphorus compounds occur in sands chiefly in the following forms:

Apatite is a phosphate and fluoride of calcium or a phosphate and chloride of calcium, with a hardness of 5 and a specific gravity of 3·17-3·23. It forms greenish or yellowish hexagonal crystals which, in some cases, are various shades of blue, grey, red, and brown, whilst white or colourless specimens also occur. It is derived partly from igneous rocks and partly from rocks which have been altered by metamorphic action. Apatite is not of wide occurrence, but occurs to some extent in the Reading beds, the Thanet sand, the Bunter beds of the Midlands, and the Lower Permian beds of Yorkshire. It has also been found in some dune sands.

Coprolite and **Phosphorite** are natural phosphate rocks which are produced by the accumulation of organic remains. Phosphates are common in the Greensand beds, some portions being so rich as to be suitable for use as fertilisers.

Phosphorus compounds effect a serious reduction in the refractoriness of silica, on account of their low fusing point and the formation of fusible phosphates. Table XXXIII., due to C. Nielson, shows the softening points of various mixtures of calcium phosphate and silica.

Table XXXIII. Fusibility of Calcium-phosphate-silica Mixtures

Formula.	Calcium Phosphate.	Silica.	Softening Point.
			° C.
	100	..	1550
	90	10	1440
$Ca_3P_2O_8 . 1SiO_2$ . .	83·8	16·2	1450
	80	20	1480
$Ca_3P_2O_8 . 2SiO_2$ . .	72·1	27·9	1500
	70	30	1445
$Ca_3P_2O_8 . 3SiO_2$ . .	63·2	36·8	1630
	60	40	1490
$Ca_3P_2O_8 . 4SiO_2$ . .	56·3	43·7	1470

Metallic Elements

Metallic elements occur in small proportions in some sands. The principal ones so found are as follows:

Gold occurs in grains of various sizes associated with zircon, corundum, topaz, garnet, etc. It is yellow or bronzy in colour, and has a hardness of 2·5-3 and a specific gravity of 12-20. It is derived from gold-bearing primary rocks, in which it occurs disseminated through the mass.

Platinum occurs as steel-grey particles, which may be either amorphous or crystalline, usually the former. It has a hardness of 4-4·5 and a specific gravity of 21·46. Platinum is derived from basic igneous rocks, peridotites, etc., though it may also be derived from some metamorphic and sedimentary rocks which have been produced originally from basic igneous rocks.

Palladium, Osmium, Iridium, Ruthenium, Iridosmine, and **Rhodium** are also found in association with platinum in detrital deposits.

Non-Metallic Elements

Non-metallic elements do not occur in sands, except carbon, which may be found in some sands, as **Diamond** (see p. 96).

Rock Fragments

Besides the simple minerals already described, small rock particles consisting of aggregates of mineral grains may occur in sands. Such rock fragments are very common in desert sands, which often consist chiefly of comminuted rock particles. In regions where crystalline schists have been disintegrated, small fragments of schist, quartzite, and granulite are often found in the sands derived from these rocks.

Organic and other Carbonaceous Matter

Carbonaceous matter occurs in most sands. It is derived from either decayed animal or vegetable matter, and may be included in the deposit as a result of the infiltration of water containing carbonaceous matter in suspension, or by the simultaneous deposition of carbonaceous matter during the period of formation of the sand, or by bituminous rocks becoming mixed with the sand. In some cases the origin of the carbonaceous matter may be readily recognised, as when leaves, wood, roots, etc., are present. The carbonaceous matter may be disseminated very uniformly through the sand or it may be concentrated in certain places. In some sands carbonaceous matter forms a thin film over the quartz and other grains present, giving the whole mass a dark-brown colour. The colour may sometimes be a guide as to the amount of carbonaceous matter present, but this is not very reliable, as other colouring

agents may influence the tint of the sand. Very dark sands, however, are frequently rich in carbonaceous matter, and when they are heated the colour may become much lighter, due to the burning off of the carbonaceous matter.

The principal effects of carbonaceous matter in sands are—

1. The colour in the raw state is very dark.

2. It has a reducing action upon any iron compounds which may be present. This action is very beneficial, as the iron compounds are reduced in process of time and converted into soluble substances which may be partially removed by infiltrating water. In this manner the iron content of the sand is gradually lowered and a partial purification takes place, so that a sand which originally might be very impure and unsuitable for purposes where a refractory sand is required might, in time, be so purified as to be suitable for such purposes. This has been especially the case with the glacial sands of Lancashire, which have been partially purified by carbonaceous matter in this way.

Many of the purest sands are associated with carbonaceous material, this association probably being partly the cause of their purity. The Fontainebleau, Lippe, and Hohenbocke sands on the Continent, and the Aylesbury sand are all very pure sands which are associated with carbonaceous matter.

Shells are a common constituent of many sands of marine origin, and in some cases they form the bulk of the deposit (p. 157).

CHAPTER V

PROPERTIES OF SANDS

To attempt to describe the properties of sands is to open out a very wide field, as sand is not a single mineral, but a heterogeneous mixture of many different ones; the innumerable combinations of these minerals in varying proportions produce sands of endless variety, so that to describe their properties fully would be a tedious and very difficult matter. It will be sufficient, however, for the purpose of this volume to describe the principal properties of a pure sand—that is, a quartzose sand—and to show how the presence of the various impurities mentioned will alter its properties, referring the reader to other parts of the book for further information as to the properties of such impure sands.

Chemical Composition.—The chemical composition of sands is very important, especially for some purposes for which sands are used. Sometimes it may only be necessary to know the percentage of silica, iron oxide, alumina, and water, whilst in other cases a more accurate and complete determination may be necessary. The analysis of a sand is usually reported somewhat as follows:

Silica	A	per cent.
Alumina	B	,,
Iron oxide	C	,,
Lime	D	,,
Magnesia	E	,,
Alkalies	F	,,
Loss on ignition	G	,,
	100	per cent.

In the first place it will be observed that the analysis adds up precisely to 100·00, a feat of skill almost impossible, even to the ablest analyst, and an almost certain sign that some constituent has been "estimated by difference." This is a convenient way of stating that the analyst has been too lazy, too busy, or too ill-paid to make a proper analysis, and having determined the silica, alumina, iron oxide, and lime, has found that a certain amount of material remains unaccounted for. He, therefore, describes this "difference" as "alkalies," and soothes his conscience

with the thought that so small a percentage of any ingr cannot make any appreciable difference in the value of the This method of working is all the more usual because the l attending the actual determination of the alkalies is almost equal to that required for all the other constituents put together.

For some purposes, such as glass-making, an accurate knowledge of the proportion of alkalies is unimportant, provided the sand is otherwise pure, but for others, such as moulding sand, the presence of lime, magnesia, and alkalies, even in small quantities, has a notable effect on the heat resistance of the sand, and their proportions should be determined with great exactitude. It is, as a matter of fact, less important to know the proportion of silica than of alkalies; and if so complete an analysis cannot be obtained, on account of the cost of the labour involved, it is better to treat the sample with hydrofluoric acid until all the silica has been driven off, and to analyse the residue, than to make a guess at the proportion of alkalies, as is so frequently done.

The composition of most sands includes 80 per cent or more of silica, together with some quantity of impurities. In very pure sands, 98 or even 99 per cent of silica may be present.

The amount of iron present in sands is often of great importance, especially where a very pure sand is required.

Mineralogical Composition.—Although the chemical composition of a sand is of great value, it is sometimes insufficient, and it may then be necessary to know in what state the various elements determined are present, as some minerals may not be harmful in a sand, whilst others may be very undesirable, or an element in some form may be undesirable, whilst if combined in another form it may not be so harmful. Thus, silica, alumina, and alkalies may be combined in the form of felspars or mica, but the felspars may be harmless or less harmful than the micas. The methods used in determining the mineralogical composition of sands are described on p. 256. The minerals present in sands have already been described in Chapter IV.

The proportion of mineral impurities in sands varies according to their mode of origin, the rocks from which they have been derived, etc. In most cases, the proportion of impurities is seldom more than 20 per cent, and it is generally much less. About 1 per cent or less is the average proportion of heavy minerals, though, where a large amount of fine material occurs, the proportion may be higher.

Sands which have been produced directly from igneous rocks usually contain a higher proportion of impurities than those which are formed by the disintegration of older sediments, as the constant transportation of detrital minerals tends to separate the grains according to their specific gravities, etc., thus concentrating the heavy minerals in certain deposits and leaving the quartz grains reasonably pure. Thus, in some of the beds of the Upper Greensand, according to Boswell, the proportion of heavy minerals is only

0·01 per cent or less. The Thanet sand contains 0·07-0·15 per cent, and the Woolwich and Reading beds 0·1-0·9 per cent of heavy detrital minerals. In the Inferior Oolite beds, the Folkestone beds, and the Bagshot sands, the proportion of heavy minerals is sometimes as much as 4 per cent, though usually it is about 0·5-1 per cent. As a general rule, the coarser sands contain a smaller proportion of heavy minerals than the finer sands.

Chemical Properties.—The chemical properties of sands vary with their nature and constitution. It is best, in considering this subject, to ascertain the chemical properties of a pure quartzose sand and then to find how these properties are affected by any impurities present.

Quartz and most forms of free silica are insoluble in all ordinary *acids*, but dissolve more or less rapidly in hydrofluoric acid in the cold and in phosphoric acid at 400° C. or at higher temperatures. Crystalline quartz is least soluble and amorphous silica the most soluble. The following results, due to Schwarz, show the proportions of crystalline and amorphous silica dissolved by hydrofluoric acid at 100° C. by digestion for one hour :

Quartz	5·2 per cent.
Gelatinous silica . . .	52·9 ,,

Felspar, leucite, and other minerals which contain a high percentage of silica are also usually dissolved very quickly by hydrofluoric acid, but anatase, brookite, rutile, andalusite, kyanite, sillimanite, staurolite, topaz, tourmaline, corundum, spinel, cassiterite, axinite, and zircon are only slowly attacked, whilst such substances as mica, hornblende, and sphene are partially decomposed.

The action of *alkalies* upon quartz and other forms of free silica is similar to that of hydrofluoric acid. Quartz is attacked to some extent by caustic soda, finely-divided material being more readily attacked than the coarse crystals. Non-crystalline silica is still more easily attacked. Colloidal and hydrated forms of silica are rapidly attacked and dissolved. Sodium carbonate also attacks quartz, but to a lesser degree.

Caustic soda decomposes felspar quickly at a bright red heat, the extent of the action depending on the size of the particles and the nature of the felspar. Fine particles are naturally more readily attacked than coarse ones, and soda felspar dissolves quicker than potash felspar.

Caustic soda also attacks hornblende, augite, biotite, etc., to some extent, but andalusite, epidote, and muscovite are not appreciably affected.

Lime does not affect silica at atmospheric temperatures, but at high temperatures (about 1000° C.) it begins to react upon amorphous silica rapidly, and though quartz and other forms of crystalline silica are not obviously attacked below a temperature of 1400° C., yet, according to J. W. Cobb, some combination does

occur (p. 191). Lime also attacks siliceous minerals in the same manner as silica.

Silica and siliceous minerals are attacked by *carbon* at all temperatures above 1200° C., forming silicon and carbon monoxide, and sometimes silicon carbide. This property is of great value in the manufacture of carborundum. The presence of iron compounds (as impurities) favours the reduction of silica to silicon.

Many of the impurities in sands are affected by chemical reagents which do not affect quartz. This property is of value in some cases for the purification of sands ; thus :

Hydrochloric acid attacks many calcareous and ferruginous impurities in sands, such as dolomite, magnesite, calcite, iron oxides, etc. Olivine, serpentine, chlorite, nepheline, epidote, leucite, apatite, and other phosphates, monazite, etc., are also attacked to some extent. Some sulphides are also dissolved. Manganese oxides, if present, are removed, and some silicates are decomposed, by prolonged boiling with the concentrated acid.

Sulphuric acid attacks any clay or hydrated alumino-silicates which may be present in sands, decomposing them into aluminium sulphate, silicic acid, etc. The action is not always complete.

Nitric acid attacks any sulphides which may be present, forming sulphates.

Chloric acid is an active oxidising agent, and attacks any carbonaceous matter which may be present in sands.

Sodium chloride (*common salt*), when mixed with sand and heated to redness, will cause the vaporisation of almost all the iron as chloride. The calcined sand, after washing to remove the soda, is thereby rendered almost free from iron compounds.

The effect of various reagents on sands, however, is not in most cases sufficiently distinct to render separation accurate, as before one substance is completely decomposed or dissolved another material may have been affected to some extent, and consequently the separation is not sharp, each constituent separated being contaminated by other substances.

Many of the minerals which occur in sands are little affected by acids and are as resistant to their action as quartz itself ; some are even more resistant (*e.g.* sillimanite and its allied minerals), so that only certain minerals, such as those previously mentioned, affect the properties of sands in the cold.

When heated, on the contrary, most mineral impurities in sands affect them more or less seriously, usually reducing the refractoriness and sometimes causing other difficulties. This effect is dealt with in greater detail in the section on the refractory properties of sands (p. 226).

Colour.—The colour of sands varies within extremely wide limits, and though it is sometimes useful, as a means of distinguishing different kinds of sand, very little reliance can be placed upon it. For instance, a dark colour in a natural sand may not necessarily mean that the sand is impure, as the colour may be due to the

presence of carbonaceous matter, which, on ignition, may possibly readily be removed, leaving a pure white quartzose sand. On the other hand, a pure white sand may contain a large proportion of colourless impurities which may make it useless for some purposes, whereas, from its colour, a dark sand might be rejected in preference to a light-coloured one.

The colour of sands may vary considerably in different strata. Thus, the top beds of a deposit may be coloured deeply by carbonaceous matter, whilst lower down the sand may be perfectly white. Another example of a change in colour of the strata is where a bed of sand is in close association with another bed containing reducing agents, such as humic acid. In such cases a brown sand may be partially bleached where it is in contact with the other bed. This may not necessarily mean a great change in composition, but simply that the iron compounds in the sand may be reduced from the ferric to the ferrous state. Many sand deposits which have been exposed to the weather for some time show various tints of yellow or brown. This coloration, or discoloration, is due to the oxidation or rusting of the iron oxide which the sand contains. The depth to which the weathering has penetrated is often shown by the colour of the deposit, and the brownish tint may become lighter at increasing depths of the deposit where the action of the weather does not occur to the same extent. The effect of weathering is particularly noticeable in soft sandy rocks, which are frequently covered with a thin layer of stained rock, whilst the interior of the mass may be much lighter in colour. The limit of weathering and discoloration is often irregular and depends to a large extent on the porosity o[illegible] deposit. Thus, the presence of a clayey sand [illegible] penetration of water, etc., and so prevent, or at any rate lessen, the discoloration of the beds below it, on account of the clay being less permeable and arresting the percolating water.

Discoloration due to weathering may be distinguished from discoloration due to change in composition or from other causes, by the fact that the former commences at the surface of a deposit and tends to be most pronounced along fissures, joints, or along the trails of plant-roots. Thus, variations in colour in different strata of sand in the same general bed may, but do not necessarily, indicate some appreciable difference in composition, nor is the colour a reliable guide to the purity of a sand, as the amount of impurity producing the colour may be quite small in proportion to the colour it produces.

The colour of sands is due partly to organic and carbonaceous matter and partly to the minerals it contains. A pure quartzite sand, or one containing only colourless impurities, such as felspar, mica, etc., will be almost pure white, whilst the presence of iron gives to the sand a yellow, red, or brownish tint, which varies according to the nature of the iron compounds present and the proportion in which they occur. Magnetite will give black sands ;

haematite, on the other hand, will give the sand a reddish tint, whilst if the iron oxide is hydrated (limonite) the colour takes various shades of yellow or brown. A greenish tinge may be seen in sands containing any appreciable proportion of iron in the ferrous state or as iron silicate. (*See below.*)

Other impurities, if present in sufficient quantity, may give characteristic colours to the sand. Thus, the Greensands owe their colour to the presence of green or brown glauconite (p. 180). Brown sands may be due to the presence of manganese. Dark-coloured sands may also be due to the presence of iron silicates such as hornblende, augite, etc., titanium minerals such as rutile, or to zircon or other dark-coloured detrital minerals. Olive-green or bluish-green colouring is usually due to the presence of ferro-magnesian minerals and their alteration-products, such as chlorite and serpentine. For further information on the nature of various coloured sands see Chapter III.

The colour of sands may change when they are heated. Thus, a dark colour due to carbonaceous matter may be destroyed, the carbon being converted into volatile compounds or into carbon dioxide, whilst any ferruginous iron which may be present may be converted into the ferric state, thus giving a light-coloured sand a darker shade. Any hydrated iron oxide, or any magnetite, which may be present may be dehydrated and oxidised, forming a red instead of a brown or black sand.

The **transparency** of sands depends on the nature of the minerals present and on the impurities which occur in them. A pure quartzite sand may consist almost wholly of clear transparent grains, but the presence of impurities may cause the grains to become opaque or clouded. The same effect occurs with other minerals such as felspar, etc., partial decomposition in the latter giving clouded grains. Thus, a sand may consist of transparent, translucent, or opaque grains according to the amount of impurities present.

In some cases, a sand may appear to consist of opaque grains which are translucent, or even transparent, when in the form of tiny fragments. Thus, the edges of black flint grains are often translucent. Dinas sand is also transparent if examined in thin sections.

The **lustre** of sands is a useful guide to their composition and to the presence of certain minerals in them. Thus, the silvery lustre of mica flakes in a sand is readily detected, whilst some other characteristic lustres are also noticeable. Quartz has a vitreous lustre, whilst metallic grains have a characteristic and unmistakable appearance. The lustre of minerals depends largely on their surface; if the latter is dull and corroded the mineral will not have so brilliant a lustre as when a perfectly new and fresh surface is examined.

Refraction.—The action of sands upon light transmitted through the grains is of great importance in determining the nature of the

constituent grains. Many crystals and grains having a crystalline structure have the power of turning a ray of light passed through them, the relative turning (or refractive) power being expressed by a figure termed the *refractive index*, which is constant for each mineral; by this means it is possible to determine the nature of some of the grains being examined. The refractive indices of the principal minerals likely to occur in sands is shown in Table XXXIV. The use of the refractive index in estimating the proportion of various minerals in sands is described in Chapter VI.

TABLE XXXIV.—REFRACTIVE INDICES

	Max.	Min.		Max.	Min.
Anatase . .	2·489		Hypersthene .	1·705	1·682
Andalusite .	1·643	1·632	Kaolinite . .	1·563	
Albite . .	1·534		Kyanite . .	1·729	1·717
Andesine . .	1·558		Labradorite .	1·555	
Anorthite . .	1·582		Lepidolite .	1·60	
Apatite . .	1·638	1·634	Leucite . .	1·508	
Augite . .	1·723	1·698	Microcline .	1·526	1·519
Barytes . .	1·647	1·636	Monazite . .	1·841	1·796
Biotite . .	1·6	1·56	Muscovite .	1·601	1·563
Brookite . .	2·741	2·583	Nepheline .	1·543	
Bytownite .	2·74		Oligoclase .	1·544	
Calcite . .	1·658	1·486	Olivine . .	1·689	1·654
Cassiterite .	2·093	1·997	Opal . . .	1·45	
Celestite . .	1·631	1·622	Orthoclase .	1·525	1·519
Chalcedony .	1·55		Phlogopite .	1·60	
Chromite . .	Very high		Pyrophyllite .	1·57	
Cordierite . .	1·544	1·535	Quartz . .	1·553	1·544
Corundum .	1·769	1·760	Rutile . .	2·903	2·616
Cristobalite .	1·484		Serpentine .	1·57	
Diamond . .	2·42		Sillimanite .	1·682	1·660
Diopside . .	1·7		Sodalite . .	1·48	
Dolomite . .	1·682	1·503	Spinel . .	1·72	
Enstatite . .	1·67	1·66	Staurolite .	1·746	1·736
Epidote . .	1·746	1·714	Strontianite .	1·52	
Fluorite . .	1·434		Titanite . .	2·008	1·899
Garnet . .	High		Topaz . .	1·627	1·618
Glaucophane .	1·639	1·621	Tourmaline .	1·64	1·62
Gypsum . .	1·53		Tridymite .	1·477	
Halloysite .	1·53		Xenotime . .	1·816	1·721
Haematite .	3·22	2·94	Zircon . .	1·993	1·931
Hornblende .	~~[illegible]~~ 1·68	~~1·68~~ 1·64			

Minerals which do not turn the ray of light to any appreciable extent are termed *isotropic*.

Some minerals are double refracting, *i.e.* they turn a ray of white light through several different angles, so that the rays are termed ordinary and extraordinary, or "fast" and "slow" rays. The maximum difference between the two rays is termed the *birefringence* of the mineral, and this value also is of use in discriminating between the constituents of sand.

Hardness.—The hardness of a sand as a whole cannot be expressed by a simple figure, as it depends on the constituent minerals present. A knowledge of the hardness or durability of sands under abrasion is chiefly required where the sand is to be used for abrasive purposes, in which case the information desired is usually

(i.) What is the hardest mineral present ?
(ii.) In what proportion does it occur ?

The abrasive action of a sand upon some other material will be equal to that of the hardest constituent, but unless the hardest constituent is the predominating one it may be undesirable. Thus, a soft abrasive containing some hard particles would be useless, as the soft abrasive would polish, whilst the harder particles would scratch. If the effect of the hard particles is desired, the softer particles are useless, and a sand containing a much larger proportion of the useful particles should be employed. The hardness of a sand must, therefore, be expressed partly as the hardness of the predominant constituent and partly as that of the hardest material present. By knowing these figures, and also the proportions of any softer minerals which may be present to a noteworthy extent, it is possible to determine the usefulness of a sand as an abrasive. Most sands consist of quartz grains which have a hardness of 7, according to Mohs' scale. Felspar is slightly less hard than quartz and is equivalent to 6 in Mohs' scale. The average hardness of most sands is 6-7. The presence of other minerals may accentuate or diminish the usefulness of a sand as an abrasive. Table XXXV. shows the hardness of the principal minerals likely to occur in

Table XXXV. Hardness of Minerals (based on Mohs' scale)

	Hardness.		Hardness.		Hardness.
Anatase	5·5-6	Felspar	6	Opal	6
Andalusite	7·5	Fluorspar	4	Orthoclase	6
Apatite	5	Garnet	7	Phlogopite	2·5
Augite	5·5	Glauconite	2	Plagioclase	6
Barytes	2·5-3·5	Glaucophane	6-6·5	Pyrites	6·5
Beryl	7·5	Gypsum	2	Quartz	7
Biotite	2·5	Haematite	6	Rutile	6·5
Brookite	5·5-6	Hornblende	5·5	Serpentine	4
Calcite	3	Hypersthene	5·5	Siderite	3·5-4·5
Cassiterite	6·5	Ilmenite	5·5	Sillimanite	6-7
Celestine	3·5	Kaolinite	2-2·5	Sphene	5-5·5
Chalcedony	7	Kyanite	5-7	Spinel	8
Chromite	6	Lepidolite	2·5	Staurolite	7·5
Columbite	6	Limonite	5·5	Titanite	5·5
Cordierite	7·5	Magnetite	5	Topaz	8
Corundum	9	Microcline	6	Tourmaline	7·5
Diamond	10	Monazite	5·5	Tremolite	5·5
Dolomite	3·5	Muscovite	2·5	Wolframite	5·5
Enstatite	5·5	Nepheline	5·5	Xenotime	4·5
Epidote	6·5	Olivine	6·5	Zircon	7·5

sands, so that their effect on any particular sand may be readily found by determining the proportion of each mineral impurity present and then referring to its hardness in the table.

If a mineral having a desired hardness occurs in a sand to a sufficient extent, it may be preferable to separate it from the other constituents and to use it in a more concentrated state. For this reason garnet, corundum, diamonds, etc., are sometimes separated from sands in which they occur.

Further information on the hardness of sands will be found in Vol. II. Chapter XIII.

Texture.—The texture of a sand is a very important property and one on which its value largely depends. Sands in general consist of a mass of small irregular grains of various sizes aggregated more or less closely together. The state of aggregation varies considerably with the situation and the various weathering actions, etc., to which the sand has been exposed. Thus, a sand may be *loose* and *incoherent*, the particles being quite separate, as in dry wind-blown sands, such as desert and dune sands. Where a quantity of clayey matter is present the sand may be slightly coherent, forming an *earthy* mass. Where the sand is partially cemented, yet still easily reduced to a powder, it may be termed *pulverulent* or *friable* according to the coherence of the particles. Where a sand has been more completely consolidated into a sandstone or sand rock it may be termed *compact*, *flinty*, *shaly*, or *foliated*, according to its structure.

In some cases, the entrance of limonite and other impurities causes the formation of crusts or hard masses in a sand deposit; these may form a rusty network of "chunks," nodules, strips, or layers which may seriously interfere with the quality and winning of the sand. Such concretionary lumps are common in some calcareous sands.

The proportion of grains of various sizes is of great importance in the use of sands, and a knowledge of the various grades present and the proportions of each is essential to the proper use of the material. In agriculture a knowledge of the coarseness of the sand grains in the soil is of great value, whilst in the filtration of water through sand-beds the grading of the sand has a great influence on the capacity of the filter—a matter of utmost importance. In brick-making, foundry practice, glass-making, and many other industries a knowledge of the grading of the sand is necessary.

The grading of loose detrital particles may be to various classifications. Table XXXVI. shows three standards which have been adopted by different workers.

These classifications are similar to one another and there is little to choose between them. In order to save confusion, however, it is best when expressing the results of a mechanical analysis of a sand to state what standard is adopted for each particular term, such as "coarse sand," "fine sand," etc.; if this is not definitely stated, difficulties may arise.

TABLE XXXVI.—CLASSIFICATION OF GRAINS

Term Applied.	Size of Particles in mm.		
	Mellor.	Boswell.	Seger.
Gravel	1·27-12·7	Over 2	..
Very coarse sand	..	1-2	..
Coarse sand	0·107-1·27	0·5-1	Over 0·33
Medium sand	..	0·25-0·5	..
Fine sand *	0·063-0·107	0·1-0·25	0·04-0·33
Superfine sand	..	0·05-0·1	0·025-0·04
Silt	0·01-0·063	0·01-0·05	0·01-0·025
"Clay" or "Dust" †	Less than 0·01	Less than 0·01	Less than 0·01

* Mellor uses the term "grit," which implies an *angular* material, so that "fine sand" is preferable, especially as "grit" is a definite geological term with another significance.

† The term "dust" suggested by Mellor is preferable to Seger's term "clay substance" or Boswell's "clay grade," as the residue usually contains other substances besides clay.

It is very convenient to have some simple means of expressing the coarseness or fineness of sands so that different samples can be compared readily. Various methods have been suggested for doing this. An ingenious method suggested by W. Jackson consists in finding a "surface factor" for each sand which serves as a basis of comparison. This factor is a single number based on the average surface of the particles, and depends on the fact that the finer the particles the greater the surface of the whole unit mass. The average diameter of such small particles may be found for particles less than 0·33 mm. diameter by multiplying the weight of the fraction whose extreme diameters are

mm.		mm.		
0	to	0·010	by	3367
0·010	to	0·025	,,	962
0·025	to	0·040	,,	518
0·040	to	0·330	,,	91

adding all the products together and dividing by 100. Thus, if a sand contained the following sized particles,

mm.		mm.	
0	to	0·010	4·5
0·010	to	0·025	10·3
0·025	to	0·040	3·0
0·040	to	0·330	82·2
			100·0

Jackson's "surface factor" is 1014, which is found as follows:

$$\begin{array}{rcrcr} 4\cdot5 & \times & 3367 & = & 15151\cdot5 \\ 10\cdot3 & \times & 962 & = & 9908\cdot6 \\ 3\cdot0 & \times & 518 & = & 1554\cdot0 \\ 82\cdot2 & \times & 91 & = & 74802\cdot0 \\ \hline & & & & 101416\cdot1 \end{array}$$

which, divided by 100, gives 1014. A finer sample would give a larger surface factor, and a coarser sample would give a smaller one. For larger sizes of particles the same principle may be applied, though it is not so accurate. Thus, the following factors may be used:

		Average Diameter.	Factor.
Passing through a No. 30 sieve	. . . .	0·4 mm.	45
,, ,, 25 ,,	. . . .	0·5 ,,	36
,, ,, 12 ,,	. . . .	1·0 ,,	23
,, ,, 5 ,,	. . . .	2·5 ,,	9

Thus, a washed sand consisting of

Particles.	Per Cent.
1·0—2·5 mm.	10
0·5—1·0 ,,	82
0·4—0·5 ,,	8
	100

will give

$$\begin{aligned} 10 \times 9 &= 90 \\ 82 \times 23 &= 1886 \\ 8 \times 36 &= 288 \\ \hline &\quad 2264 \end{aligned}$$

and would have a surface factor of only 22·6.

In English measure, the factors are as shown in Table XXXVII.

TABLE XXXVII.—SURFACE FACTORS *

	Sieve.	Diameter of Particles.	Nature.	Factor.
A	On Sieve No. 1	Above 0·5 in.	Stones	Nil.
B	Between Sieves Nos. 1 and 10	,, 0·05 -0·5 in.	Gravel	0·27
C	,, ,, 10 ,, 50	,, 0·01 -0·05 in.	Coarse sand	2·6
D	,, ,, 50 ,, 100	,, 0·005 -0·01 in.	Medium sand	13·2
E	,, ,, 100 ,, 200	,, 0·0025-0·005 in.	Fine sand	22·6
F	,, ,, 200 ,, washing	,, 0·0004-0·0025 in.	Silt	53·9
G	Washed out by a stream 0·43 in. per minute	Below 0·0004 in.	Clay and dust	359·0

* The sieves in this table are standard sieves in which the diameter of the wires exactly equals that of the apertures.

If the weight of each fraction be represented by the letters in the first column in the above table, the surface factor is

$$0{\cdot}27B + 2{\cdot}6C + 13{\cdot}2D + 22{\cdot}6E + 53{\cdot}9F + 359G.$$

The figures in Table XXXVIII. show the surface factor of several well-known sands in accordance with the factors in Table XXXVII.

TABLE XXXVIII.—SURFACE FACTORS OF MOULDING SANDS

Sand.	A.	B.	C.	D.	E.	F.	G.	Surface Factor.
Medium Erith .	..	0·03	1·19	0·34	42·74	28·52	27·17	12,205
Fine Mansfield .	..	..	1·50	3·92	40·63	31·73	22·21	10,657
Coarse Mansfield	0·01	0·74	3·36	18·42	67·17	6·49	3·81	3,497
Stourbridge .	..	0·22	5·36	18·93	54·76	14·64	6·08	4,472

This method is generally accurate enough for most purposes, but Mellor has shown that the arithmetical mean of the limiting diameters is not the true average diameter of the fractions and that a truer value is

$$\text{Average diameter} = \sqrt[3]{\frac{(D+d)\,(D^2+d^2)}{4}},$$

where D is the maximum diameter and d is the minimum diameter in any given fraction.

He has also suggested that the surface factor should be calculated from the formula

$$\frac{6}{S}\left(\frac{W_1}{d_1}+\frac{W_2}{d_2}+\frac{W_3}{d_3}+\ .\ .\ .\right),$$

where S denotes the mean specific gravity of the powder, W_1, W_2, W_3, . . . the respective weights of the fractions, 1, 2, 3, . . . per unit weight of powder (commencing at the finest), and d_1, d_2, d_3, . . . the corresponding average diameters of the grains in the respective fractions.

A method adopted by the American Foundrymen's Association for expressing the relative fineness of sands consists in multiplying the weight of sand passing through each mesh and being retained by the next smaller mesh, by the number of the mesh, and dividing the sum of these products by 100. Thus, suppose a sand consists of

Over 20-mesh	2·8
20-40 ,, ...	40·0
40-60 ,, ...	27·2
60-80 ,, ...	9·6
80-100 ,, ...	4·8
Less than 100-mesh . . .	15·6
	100·0

the calculations would be as follows:

2·8 × 0	..
40·0 × 20	800
27·2 × 40	1088
9·6 × 60	576
4·8 × 80	384
15·6 × 100	1560
	4408

which, divided by 100, gives 44·08. This method is quite simple and is satisfactory for most purposes, for, though the figures obtained do not agree with those of other methods, they are comparable among themselves.

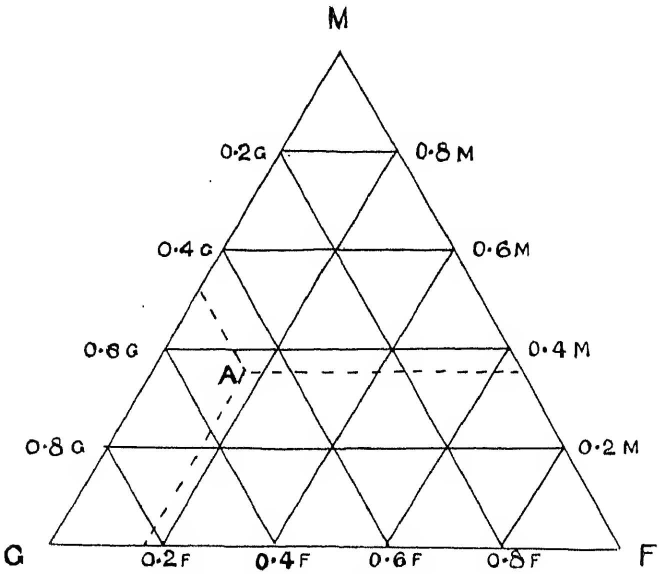


Fig. 10.—Feret's triangular diagram.

Another method of representing the mechanical composition of sands, proposed by M. Feret,[1] is shown in Fig. 10. M. Feret separates the sand to be tested into three grades as follows:

Grade.					Description
Large (G)	passing through	5 mm.	(0·2 in.) holes or	approximately	5-mesh.
	retained by	2 ,,	(0·079 in.)	,, ,,	15-mesh.
Medium (M)	passing through	2 ,,	(0·079 in.)	,, ,,	15-mesh.
	retained by	0·5 ,,	(0·020 in.)	,, ,,	46-mesh.
Fine (F)	passing through	0·5 ,,	(0·020 in.)	,, ,,	46-mesh.

He calculated the percentage of each sand as a proportion of 1 and plotted the composition of the sand on a triangular diagram as shown in Fig. 10.

[1] M. Feret, *Annales des Ponts et Chaussées*, 1896.

In this triangle a series of lines is drawn parallel to each side, and each side may be used in turn to indicate the proportion of particles of each grade. Thus, a sand composed of

48	per cent of	coarse grains (grade G)
35	,,	medium grains (grade M)
17	,,	fine grains (grade F)

would be represented by the point *A* (Fig. 10). The point *G* is taken to represent a sand composed wholly of grade G, so that, starting with the line *FM* as a base and proceeding towards *G*, the point representing 48 per cent of grade G must lie somewhere between the line 0·4 G. and 0·6 F. and the line 0·5 G.-0·5 F. Similarly,

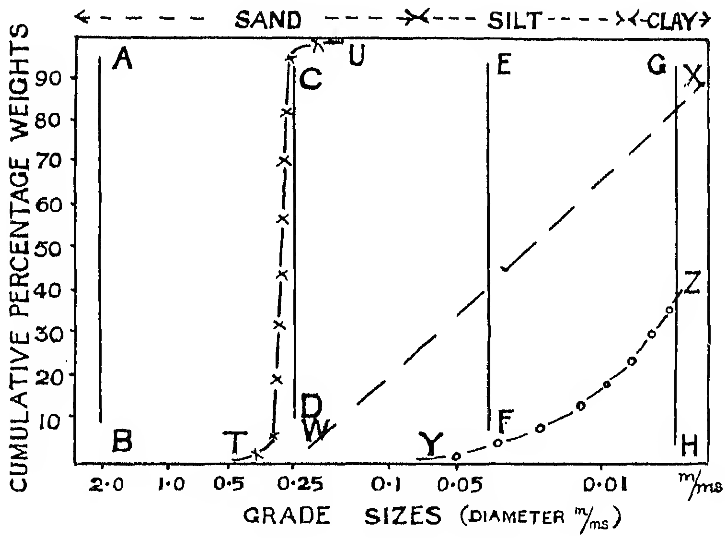


FIG. 11.—Boswell's grading graph.

the point representing 35 per cent of grade M must be between the line 0·6 G.-0·4 M. and the line 0·7 G.-0·3 M.; and the point representing 17 per cent of grade F must lie between the lines 0·1 F.-0·9 M. and 0·2 F.-0·8 M. The single point *A* which fulfils all these conditions represents the granulometric composition of the sand.

A very convenient method by means of which the coarseness or fineness of different sands can be compared is that adopted by Boswell, in which the limits of grade size are marked off in a graph horizontally as abscissae (proportionally to the logarithms of the diameters of the particles), and the "cumulative percentage weights" of the grades vertically as ordinates. By this method graphs are obtained similar to those shown in Fig. 11. A sand in which all the grains are of uniform size would be represented

by a vertical line, such as *AB*, in which all the particles are 2·0 mm. diameter, *CD* would represent a sand with particles all 0·25 mm. diameter; *EF* a silt having all the grains 0·045 mm. diameter, and *GH* a "clay" with all the grains 0·005 mm. diameter. Such compositions are not found in nature, but their typical positions are shown. The curve *TU* represents a sand, from Kynance Cove, Cornwall, in which the grain size is very uniform, but not entirely so. The curve *WX* is a loam or a mixture of sand and clay, and is, consequently, much flatter, whilst the glacial clay *YZ* is even more so. A comparison of curves of sands produced in this way readily shows their general characteristics in a very convenient manner.

Fuller plots the mechanical analyses of sands on a graph in

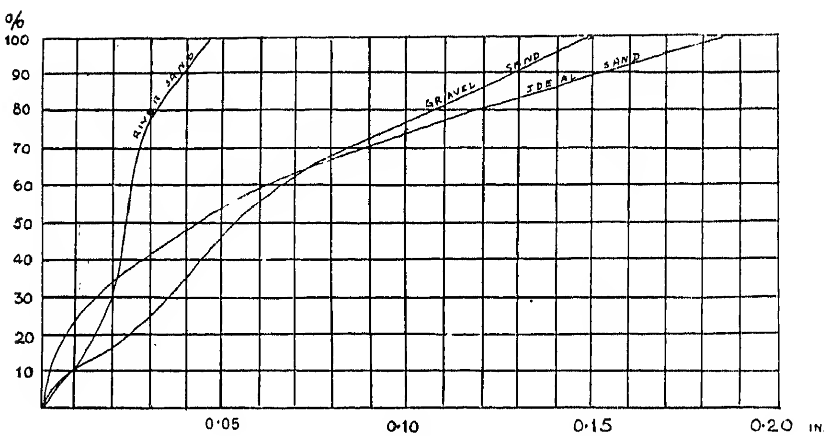


FIG. 12.—Fuller's grading graph.

which the percentages of particles are marked on the abscissae and the sizes of the grains in inches on the ordinates. He found that the graph of a perfectly graded sand was in the form of a parabola constructed according to the formula

$$d = \frac{P^2 D}{10{,}000},$$

where D is the largest diameter of particles, *d* is any given diameter, and P is the percentage of the mixture smaller than *d*. Fig. 12 shows the graphs of three sands plotted in this manner, including a perfectly graded mixture.

In most sands, the particles of heavy minerals are smaller than the average quartz and felspar grains, as the speed of the wind or water required to move a quartz grain of a certain size will not move a heavy mineral grain of the same size. Consequently, sands

and similar deposits contain a larger proportion of heavy mineral grains among the finer grades of sand. In the dune sand of the Balgownie Links, near Aberdeen, Boswell found that practically the whole of the heavy minerals are contained in the fine sand, these heavy mineral grains varying from 0·1 mm. to 0·25 mm., whilst the size of the quartz grains is from 0·25 mm. to 1 mm. According to Gilligan, almost the whole of the heavy minerals in the Millstone Grit will pass through a 90-mesh sieve.

The mica grains present in sands are usually much larger than the average size of the heavy minerals present, on account of their flaky nature which enables larger fragments to be carried by wind or water than would be the case if the grains were more compact, as are those of the heavy minerals present. The mass of the mica grains is, however, generally less than that of the more compact minerals.

Table XXXIX., due to Boswell, shows the size of the mica grains in various sands compared with the size of the heavy minerals present.

TABLE XXXIX.—SIZES OF MICA AND HEAVY MINERAL GRAINS

	Muscovite.	Other Heavy Minerals.
	Mm.	Mm.
Bunter Pebble Bed . . .	0·5	0·25
Yeovil Sands . . .	0·25	0·06
Lower Greensand . .	0·60	0·25
Thanet Sand . . .	0·15	0·04
Claygate Beds . . .	0·15	0·05
Cray Boxstones . . .	0·55	0·20
Lenham Beds . . .	0·40	0·20

The relative fineness of the various sands used in this country has not been investigated to any great extent and there is comparatively little information available. Some of the best investigations which have been carried out as yet have been made by P. G. H. Boswell, with a view to determining the use of sands for glass-making and other purposes.

Further information as to the grading of particular sands will be found in later chapters.

The **shape** of the grains in a sand may vary from sharp angular forms which have not been abraded to any great extent, to highly abraded and fully rounded grains. Sorby has classified sands into the following grades with reference to the shape of the grains present:

1. Fresh angular grains derived from the breaking up of granitic or schistose rocks (Fig. 13) and the slightly less angular fragments often known as "sub-angular" grains (Fig. 14).

2. Well-worn sand in rounded grains, the original angles being completely lost (Fig. 15).
3. Sand having the grains chemically corroded so as to produce a peculiar texture, different from that of worn grains of crystals.
4. Sand with a perfect crystalline outline (Fig. 16).

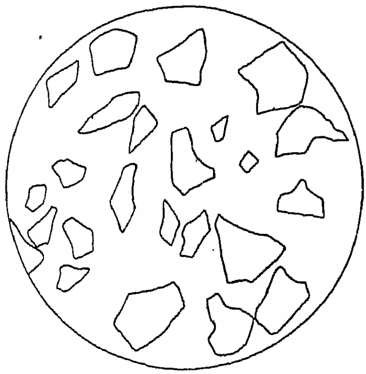


FIG. 13.—Angular grains.

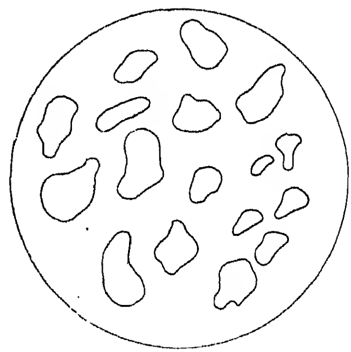


FIG. 14.—Sub-angular grains.

Sands which have been produced by the simple disintegration of rocks *in situ*, or which have not been moved to any great extent, generally consist of sharp angular grains if the rock from which

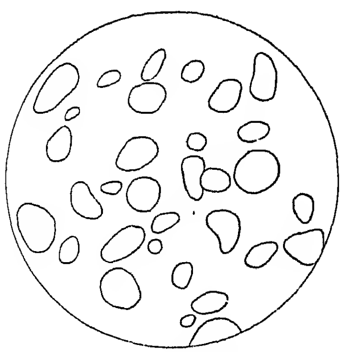


FIG. 15.—Rounded grains.

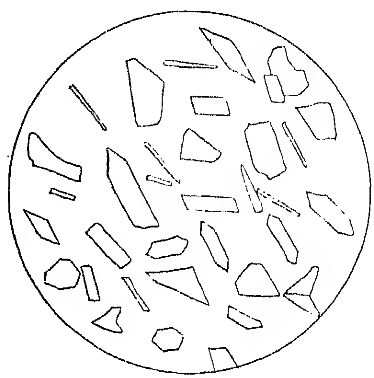


FIG. 16.—Crystalline grains.

they have been formed consists of such grains cemented together. If the rock from which they have been formed consists of rounded grains, the sand will likewise consist of rounded grains, but sand produced by the disintegration of igneous and metamorphic rocks

usually consist of sharp angular grains. Glacial sands are usually quite sharp and angular. This is due to the fact that the abrasion to which they are subjected is more in the nature of sliding than rolling, so that their angular outlines tend to be preserved.

Sands which are subjected to continual attrition by transportation from place to place gradually lose their angular forms, the corners becoming worn and forming sub-angular, or even round grains. The extent to which the grains are rounded is a good indication of the extent to which they have been subjected to abrasion.

Sometimes grains of sand may be rounded to some extent, and then cemented into a solid stone by the infiltration of a cementing medium such as lime, iron compounds, etc., the stone being afterwards broken up, and the resulting grains again subjected to abrasion, thus causing further rounding. Hence, the rounding of the grains may continue through various geological periods until the angularity is entirely lost. The sand found in some pot-holes, where it has been continually abraded for a very long period of time without being able to escape, is very much rounded in this way.

Some minerals, even after prolonged abrasion, do not acquire rounded outlines. Thus, mica splits into thin laminae or flakes, but never forms rounded grains. Other minerals have definite cleavage planes and tend to break into particles of smaller size, but always retaining an angular form. Calcspar is a typical example of this. Organic shell-remains, even after long-continued attrition, also retain their angular outlines.

Some accessory minerals are "included" in quartz grains during part of their journey, and are protected by the surrounding quartz and so are less rounded than similar grains which have been exposed for the same time to abrading actions.

The degree of rounding which sand grains undergo depends on the following conditions: (*a*) the volume of the particle; (*b*) its specific gravity, SG; (*c*) the distance travelled, D; (*d*) the velocity of movement, V; and (*e*) its hardness. The amount of rounding by wind action may be calculated by the following formula:

$$R = \frac{\text{Volume} \times SG \times D \times V}{\text{Hardness}},$$

and that for water action by the following:

$$R = \frac{\text{Volume} \times (SG - 1) \times d \times v}{\text{Hardness}}.$$

The most rapid cause of the rounding of sand grains is when they are carried by wind, as in the formation of desert sands. The particles composing such sands are continually coming into violent contact with each other, and with other rocks, and are rapidly rounded, forming a characteristic type termed "millet seed" sand on account of the perfect rounding of the grains.

Some of the Bunter sands of Lancashire and Cheshire flow through the fingers like shot. These sands have probably been formed on a Triassic desert.

The grains of dune sands along the sea coasts are not so rounded as desert sands, as, although they have been accumulated by the action of the wind, the abrasion has not been sufficiently prolonged to cause very much rounding of the particles. The difference between the roundness of the grains of sand formed in water and in aeolian deposits is well shown in Table XL., by Dr. Mackie.

TABLE XL.—ROUNDING OF GRAINS

		Percentage of Grains.		
		Angular.	Sub-angular.	Rounded.
Water	River sand from crystalline rocks. River Spey	Nearly all	Few	..
	Beuth sand near mouth of Spey (Lossiemouth)	35	42	23
	Garnetiferous black shore sand (Macduff)	48*	23	29
Desert air	Dune sands (Cublin)	20	30	50
	Reptiliferous sandstone, Triassic	5	19	76

* Due to the presence of garnet.

The relation between the amount of rounding sustained by water and air action may be expressed by the formula

$$\frac{R}{r} = \frac{SG \times D \times V}{(SG - 1) \times d \times v},$$

where R equals rounding by wind action, r equals rounding by water action, SG equals specific gravity of material, D equals distance travelled in air, V equals velocity in air, v equals velocity in water, d equals distance travelled in water.

The apparent specific gravity of a particle in air is always greater than that in water, and the velocity of movement is also much higher. The distance travelled by the grains is very difficult to estimate, as in air they may be carried for great distances, whilst in water the cumulative effect of many rollings backwards and forwards, or of short swirls, may exceed the effect of a great distance travelled by wind-blown grains. The smallest grains of sand formed in rivers and seas are much less rounded than the larger ones, as the former are more buoyant and are held longer in suspension, so that they are not exposed to the same amount of attrition as the heavier grains which remain at the bottom. Another reason for the less rounding of small grains of sand, especially when they are in water, is that a film of water protects each grain from impact.

In air the size at which no further rounding takes place is far smaller than in water, though its actual limits are not definitely known. According to Holmes, the smallest rounded aeolian particles are between 0·03 and 0·04 mm. in diameter, whilst the smallest water-worn particle recorded is 0·5 mm.

The rounding of grains of other minerals may also depend on the frequency with which they come into contact with grains as hard as, or harder than, themselves. If such occurrences are infrequent, the grains tend to remain angular.

The extent of rounding of the grains varies also according to the nature of the material composing the grain. They may be angular as a result of their hardness, or because they have not been weathered to any great extent, or they may be of aeolian origin. On the other hand, they may be rounded to a greater or less extent as a result of water action or on account of their softness.

The shapes and sizes of grains in a sand are very important for some purposes, and whilst grains of certain sizes may be very desirable in some industries, they may be quite unsuitable in others. Thus, for building purposes, a clean sharp sand with grains of many sizes is desirable, rounded grains being of little value, but for glass-making a uniform round-grained sand is most valuable. The particular characteristics of sands for special purposes are described in Vol. II. under the various industries for which they are used.

Specific Gravity.—The specific gravity of a sand is the average weight of its particles considered separately, relative to that of an equal volume of water. The use of the term "specific gravity" is restricted to that of the grains themselves and does not take into account the air-spaces between the particles. A figure which relates to a mass of sand and includes the air-spaces is termed the "apparent specific gravity" or "volume-weight."

The specific gravity of a pure quartzose sand is equal to that of quartz, namely 2·65, but the presence of other minerals may change this to a greater or less extent, according to the amount of impurity present and the specific gravities of the various constituents. Usually, the specific gravity of ordinary sands is between 2·5 and 2·7.

Siliceous sands containing silica in forms other than quartz may have a less specific gravity, as shown below:

	Specific Gravity.
Quartz sand	2·651
Geyserite	2·651
Flint	2·632
Chalcedony	2·607

Density is a term which is often used very loosely in connection with sand. Strictly speaking, it relates to the specific gravity of the particles forming the mass, but it is occasionally used to indicate impermeability, a sample of sand being, in this sense, said to be dense because air or water will not penetrate easily into it. Occasionally, the term density is used as distinct from specific

gravity to indicate the relative weight of the whole mass, and not that of each particle considered separately, or the average of all such particles. In this sense, the density changes with the treatment undergone by the sand, whilst the specific gravity remains constant. It is far better in such cases to employ the term volume-weight, as, although this is more cumbersome, it indicates more clearly the meaning of the figure, *i.e.* the weight of a mass of ascertained volume, that of an equal volume of water being taken as unity. The volume-weight of sands is usually about 1·9, but varies according to the sizes of the particles and the extent to which the mass has been compressed.

Weight.—The weight per cubic foot of sand varies according to the nature of the minerals it contains, the size and shape of the particles, and the pressure, if any, to which the mass has been subjected. On an average, 1 cubic foot of loosely heaped sand will weigh 120 lb., but this figure is of general rather than particular application. For example, the following figures were obtained with typical sands from three different sources:

River sand . . .	118 lb. per cu. ft.
Pit sand	102 ,, ,,
Thames sand . . .	103 ,, ,,

Sand containing moisture has a smaller weight per cubic foot than dry sand, as each grain of sand coated with a thin film of water has a slightly greater volume than that of the dry grains. This decrease in weight is specially noticeable in the case of fine sand, as it has a greater capacity for receiving films of water on account of the greater surface area of the grains relative to their mass. As the size of the grains increases, the difference in weight is less and less marked, until with particles of gravel ½ in. or more in diameter the effect is practically nil.

Very wet sand may weigh more than the same volume of the same sand when only slightly moistened, as the excess of water will occupy the interstices between the particles which would otherwise be filled with air. This may easily be shown by weighing a box filled with dry sand, and then pouring in as much water as the sand will absorb without any appreciable increase in volume, and then re-weighing it. On allowing such a wet mass to drain, the excess of water will run away, leaving a moist mass which has a slightly less weight per cubic foot than the same sand when dry. The effect of water in increasing the volume of a sand and, consequently, of decreasing its volume-weight has been investigated by Fuller, who found that the maximum volume is attained with about 6 per cent of moisture.

Porosity.—The term "porosity" is sometimes confused with permeability, but this should be avoided, and the term porosity confined to the proportion of pores, voids, or interstices in a mass of sand. These pores are the spaces (usually filled with air) between the solid particles, the porosity of a sand varying with the size and

shape of the particles of which it is composed. Sands with the greatest porosity are those composed of moderately large and wholly rounded grains, as sharp and angular particles interlock and so give less pore-space than those which have rounded outlines. Sands composed of particles of several different sizes will be less porous than those containing only one size, as the smaller particles occupy some of the spaces between the larger ones which would otherwise be empty.

The porosity of a sand will also vary according to the extent to which it has been compressed, and the lower portion of a heap, or deep bed of sand, will be less porous than the upper portion on account of the pressure being greater at a greater depth. Hence, a sample of sand as received at a laboratory is not a reliable guide as to its porosity, either in the original deposit or in actual use.

Porosity may be expressed in either of two ways:

(*a*) As a percentage *by weight*, which is an indirect and somewhat misleading expression, as it really indicates the weight of water absorbed by one hundred units of weight of sand. Thus, a sand is said to have a porosity of 37·7 per cent by weight, if 100 lb. of the sand absorb 37·7 lb. of water.

(*b*) As a percentage *by volume*, which is a much more rational expression, as it indicates the relation of the volume of the pores to the volume of the whole mass. Thus, a sand having a porosity of 50 per cent by volume contains equal measures of air-spaces and sand.

The relation of the percentage by weight to that by volume may be found by the following formula:

$$P_w = \frac{100\ P_v}{(100 - P_v)S},$$

where P_w equals the porosity per cent by weight, P_v equals the porosity per cent by volume, and S equals the specific gravity of the sand.

This is further shown by the following example:

A sand having a porosity of 50 per cent by volume contains
50 c.c. of air,
50 c.c. of solid sand.
Now 50 c.c. of air would be occupied by 50 g. of water.
50 c.c. of solid sand would be occupied by 50 × 2·65 = 132·5 g. of sand.
But a sample of sand weighing 132·5 g. and absorbing 50 g. of water in its pores would have a porosity by weight of

$$50 \times 100 \div 132{\cdot}5 = 37{\cdot}7 \text{ per cent by weight.}$$

In other words, if $P_v = 50$ and $S = 2{\cdot}65$,

$$P_w = \frac{100 \times 50}{(100 - 50)\ 2{\cdot}65} = 37{\cdot}7.$$

When estimating the porosity of a sand, as large a sample as possible should be used, and prior to testing it should be rammed, compressed, or otherwise treated so as to bring it as nearly as possible to the condition in which it will be used; otherwise serious discrepancies may occur.

Permeability is the facility with which gases and liquids pass through a material. The permeability of sands to liquids and gases is an important property where sands are used for filters, moulding, etc. It depends chiefly on the size and shape of the particles and on the amount of clayey matter present. The most permeable sands are those with rounded grains of uniform and moderately large size, and with the smallest possible percentage of clay. The presence of angular particles, small grains, or clay reduces the permeability roughly in proportion to the amount present.

Magnetic Properties.—The magnetic properties of sands depend very largely on the nature of the constituent grains. A pure quartzose sand is non-magnetic, as the constituent grains of quartz are not attracted by a magnet. Some of the impurities in sands are, however, magnetic to varying extents. Table XLI. shows the relative magnetic powers of some of the principal minerals found in sands.

TABLE XLI.—MAGNETIC PROPERTIES OF MINERALS

Highly Magnetic.	Moderately Magnetic.	Feebly Magnetic.	Almost Non-magnetic.	
Magnetite.	Hypersthene.	Chlorite.	Zircon.	Barytes.
Titanoferrite.	Augite.	Staurolite.	Corundum.	Most iron-free minerals.
Ilmenite.	Garnet.	Epidote.	Galena.	
Pyrrhotite.	Siderite.	Limonite.	Fluorite.	
Haematite.	Olivine.	Actinolite.	Pyrite.	
	Hornblende.	Kyanite.	Cassiterite.	
	Chromite.		Rutile.	

Electrical Conductivity.—The conductivity of sands for electricity varies according to the nature of the constituents present (see Table XLII.).

TABLE XLII.—ELECTRICAL CONDUCTIVITY

Good Conductors.	Moderate Conductors.	Bad Conductors.	
Magnetite.	Ferriferous amphiboles and pyroxenes.	Siderite.	Phlogopite.
Titaniferous magnetite.	Biotite.	Xenotime.	Muscovite.
Magnetic haematite.	Tourmaline.	Epidote.	Tremolite.
Pyrrhotite.	Titanite.	Olivine.	Apatite.
Chromite.	Rutile.	Staurolite.	Andalusite.
Ilmenite.	Anatase.	Garnet.	Sillimanite.
Haematite.	Brookite.	Monazite.	Fluorite.
Wolframite.	Cassiterite.	Gypsum.	Diamond.
Spinel.		Quartz.	Topaz.
Ferriferous cassiterite.		Chalcedony.	Spinel.
Tantalite.		Felspars.	Kyanite.
Iron pyrites.		Calcite.	Corundum.
Gold.		Dolomite.	Celestite.
		Cordierite.	Zircon.
		Barytes.	

The electrical conductivity of some of the constituents of sand is of great value in its purification. This property is dealt with in greater detail in Chapter IX.

Viscosity.—The viscosity or resistance to flow of sands is sometimes very important. It depends on the size and shape of the particles. A sand consisting of angular grains will be very viscous, as the grains will interlock; but a sand consisting of rounded grains will flow easily, as the grains slide over each other quite readily. Thus, some of the Bunter sands will flow through the fingers like shot on account of the roundness of the particles. The viscosity of a sand is also dependent, to some extent, on the amount of clay present in it. If there is sufficient plastic clay to coat each particle of non-plastic material, the sand may be held together in a fairly strong cohesive mass, whereas if the clay were not present the sand would be incoherent and less viscous. Sands containing various proportions of clayey matter are suitable for different purposes, such as moulding, whilst for other purposes, such as for use as building sand, the cohesion of the particles is very undesirable.

The viscosity of a sand may be strikingly shown by fastening a thin piece of cigarette paper over the lower end of a long vertical glass tube, into which sand is then poured. The sand will not press with sufficient weight on to the paper to break it; and even if a heavily weighted plunger is applied to the sand the paper will not be damaged. The viscosity of the sand and the interlocking of the grains create so great a horizontal pressure that the full pressure is not applied to the paper.

Toughness.—The toughness of a sand depends on the proportion of clayey matter present, and is an important factor in some industries, especially in foundry practice. This property is dealt with in greater detail in Vol. II. Chapter VI.

Deformability.—The deformability of a sand is the force required to effect a definite alteration in its shape. This is dependent on the cohesion of the sand, and on the proportion of clay present; it is an important property in moulding sands (see Vol. II. Chapter VI.).

Compressive Strength.—The compressive strength of a sand depends on the size and shape of the particles and the amount of binding material present. Sands with angular grains will have a greater compressive strength than those with rounded ones, as the particles will interlock and flow less readily. Clay, if present, will bind the particles of sand together, and so increase the compressive strength to an extent corresponding roughly to the proportion of clay present. The crushing strength is least with wet sand, rather greater with dry sand, and greatest after the sand has been baked. These increases in strength are due solely to the corresponding changes in the clay present in the sand.

Refractory Properties of Sands

The properties of sands when heated to high temperatures are very important for some of the purposes for which sands are used.

When amorphous silica is heated, it is slowly converted into the crystalline form. This conversion is hastened by pressure, or by the presence of fluxes such as sodium carbonate, fluoride, silicate, etc., as well as by sodium tungstate and alkali phosphates. The action of heat on crystalline silica (quartz) has the effect of producing other allotropic forms; thus, when quartz is heated to a temperature of 200°-275° C. a change occurs and α-quartz is produced. On heating to 575° C., the α-quartz is converted into β-quartz. This change is accompanied by considerable changes in the properties of the quartz, and there is also, according to White, an endothermal reaction of 4·3 cal. gr. per gram. β-quartz crystallises in the hexagonal system, and consequently can be discriminated from α-quartz when examined under polarised light. The transformation is reversible, and if the quartz is cooled, it is reconverted into the α-state, which is slightly different from the natural quartz.

If the heating is continued above 575° C., a further change in allotropic form occurs and cristobalite or tridymite is produced, particularly at 1100°-1300° C., though there is a considerable amount of uncertainty as to the conditions under which these two allotropic forms are produced. The rate of conversion depends largely on the size of the particles, as well as on the temperature and duration of heating, as small grains are converted into tridymite and cristobalite much more rapidly than larger particles. For the same reason, amorphous silica is more rapidly converted than crystalline quartz, as the minute grains of the former are more easily affected by heat.

Table XLIII.[1] shows the specific gravity of various forms of silica after repeated heating. The specific gravity is a reliable test of the amount of conversion, and it will be seen that the amorphous forms of silica attain a maximum specific gravity very quickly, whilst the crystalline forms invert much more slowly.

Whilst it is possible to produce tridymite and cristobalite by heating quartz or free silica alone, the action is very slow; it is hastened by the presence of impurities in the sand, so that the conversion is much more rapid in the presence of fluxes than in a pure quartzose sand.

Effect of Impurities on Inversion.—Le Chatelier and B. Bogitch have shown that the various non-siliceous materials which increase the rapidity of conversion may be classified as follows:

(i.) Molten silicates (*i.e.* fusible substances which at the temperature of heating become molten) which dissolve the quartz grains and cause the silica to recrystallise as tridymite at about 1200° C. The same substances, on prolonged heating, dissolve some of the

[1] Rieke and Endell, *Silikat-Zeitschrift*, 1913, No. 2.

TABLE XLIII.—EFFECT OF REPEATED HEATING ON SILICA

	Specific Gravity.											
Number of times heated	Raw	1	2	3	4	5	6	7	8	9	10	11
Quartz from Norwegian pegmatite (in pieces)	2·65	2·38	2·33	2·325	2·33	2·32	2·31	2·32	2·33	..	..	..
Do. (in fine powder)	2·65	2·37	2·34	2·34	2·335	2·33	..	..	..	..	..	..
Quartz sand from Hohenbocke	2·651	2·591	2·502	2·456	2·450	2·442	2·428	2·386	2·369	2·343	2·338	2·328
Pure geyserite from Taurus	2·651	2·555	2·492	2·478	2·391	2·394	2·366	2·344	2·321	2·316	2·313	..
Average geyserite	2·651	2·456	2·361	2·349	2·333	2·317	2·306	2·307	..	..	..	..
Quartz crystal (St. Gothard, in pieces)	2·65	..	..	..	..	2·64	..	..	..	..	2·63	..
Do. (in powder)	2·65	2·568	2·553	2·547	2·519	2·475	..	..	..	..	..	..
Flint (in pieces)	2·632	2·231	2·241	2·248	2·239	2·233	2·255	2·251	2·231	2·230	..	..
Chalcedony (in pieces)	2·607	2·16	2·17	2·17	2·19	..	..	..	..	..	..	..
Hydrated silica (Kahlbaum)	..	2·322	2·319	2·312	2·316	2·317	..	..	..	..	..	..
Quartz glass (Haraeus)	2·21	2·327	2·328	2·33	..	..	..	..	..	..	..	..

tridymite and cause it to recrystallise at a temperature of 1500° C. as cristobalite.

(ii.) Other natural impurities which may not melt, yet increase the rapidity of conversion.

(iii.) Foreign vapours which diffuse into the grains and so increase the rate of conversion. The vapours of some iron compounds are very active in this direction, as is shown by the action of flue-dust upon siliceous materials.

The action of molten materials in hastening the conversion depends to some extent on the viscosity of the liquid. The more viscous the molten material the slower is the reaction, whilst, conversely, a very fluid liquid increases the velocity of the conversion. For this reason, molten calcium silicates, which are extremely mobile, greatly increase the speed of conversion ; sometimes the speed is so great that the quartz is converted directly into cristobalite without any tridymite being formed.

Seaver has found that, under the conditions necessary to convert 48·95 per cent of the silica in silica bricks in the absence of lime, no less than 77·35 per cent would be converted if lime were present. The relative activity of various impurities in hastening the conversion of the silica is given by A. Scott as follows, in their order of merit :

Iron oxide, lime, magnesia, titanic oxide, alumina, sodium and potassium silicates, chlorides, and carbonates.

Sodium tungstate, sodium phosphate, and lithium chloride also appear to facilitate the conversion of quartz into tridymite.

In most cases, though not in all, the presence of more than one oxide renders the conversion more rapid than if only one is present.

Effect of Temperature on Inversion.—Although a high temperature increases the rapidity with which the conversion takes place, it is not essential, as, provided the duration of the heating is sufficiently long, the whole of the silica may be completely converted at the lowest temperature at which the conversion commences. Ferguson and Merwin found that the minimum temperature necessary for the conversion of quartz into tridymite is 870° C., the rate increasing with the temperature. At a temperature of about 1300° C. the reaction is fairly rapid, and at 1410°-1435° C. it attains a maximum rapidity. Rieke and Endell confirmed these figures, but found that a considerable amount of conversion occurs below 1000° C. ; they could not find any definite temperature which could be described as a minimum, owing to the slowness of the reaction.

When tridymite is heated to a temperature of 1470° C. or over, it tends to be converted into cristobalite.

The formation of cristobalite is a subject of much controversy. At the temperature mentioned above, C. N. Fenner states that only cristobalite is formed, even when fluxes, which are supposed to favour the formation of tridymite, are present. Day and

Lacroix have produced cristobalite by heating to a temperature of about 1500° C., whilst above this temperature Endell has produced cristobalite in the presence of lime, alumina, and iron oxides. Minute particles of carbon appear to facilitate the production of cristobalite by acting as nuclei around which the crystals form.

Insley and Klein claim that when silica is heated, cristobalite is always produced first, but that after prolonged heating at temperatures below 1470° C. tridymite may be formed. Bleininger and Ross have found that at 1500° C. about 90 per cent of the silica in silica bricks is converted into cristobalite, but Seaver found practically no tridymite at 1630° C.

Table XLIV., due to Seaver, shows the effect of heating coarsely ground quartz to a temperature of 1450° C. for forty hours one or more times:

TABLE XLIV.—EFFECT OF HEAT ON COARSE SILICA

Treatment.	Percentage of Quartz and Calcium Silicate.	Cristobalite.
After first firing	50·57	48·95
After second firing . . .	31·38	68·62

If the quartz is more finely ground, as in the case of that used for the manufacture of silica bricks, a much greater conversion takes place, as is shown in Table XLV., due to the same worker.

TABLE XLV.—EFFECT OF HEAT ON FINE SILICA.

Treatment.	Percentage of Quartz and Calcium Silicate.	Cristobalite.
After first firing	22·65	77·35
After second firing . . .	17·13	82·87
After third firing . . .	16·02	83·98

H. Le Chatelier regards cristobalite as metastable at all temperatures below its fusing point, and suggests that it is only formed under special conditions, and that it reverts to tridymite when such conditions are not present.

Fusibility.—When any of the three forms of silica mentioned are heated to a sufficiently high temperature they are converted into amorphous (fused) silica. If the heating of the silica is sufficiently slow, the material may pass through its various allo-

tropic forms before fusion, but where the heating is very rapid, fusion may take place direct from the quartz, the formation of other allotropic forms not being recognisable. The temperature at which silica fuses depends upon the proportion of impurities present and on the size of the pieces of material. When in a finely powdered state and heated slowly, pure quartz fuses at about 1500° C., pure tridymite at 1670° C., and pure cristobalite at 1625° C.

When fused silica is cooled slowly, it reverts into one or other of the allotropic forms of crystalline silica, but if cooled rapidly it may solidify without reversion. The latter is the more general action, but if the glass is maintained for a long period at a temperature above 1000° C. but below its melting point, crystallisation takes place and cristobalite may be formed. Several hours' heating at 1500° C. will effect this change. The reversion to tridymite may also occur if the conditions are suitable. Le Chatelier found that, on being maintained for twenty days at a temperature of about 800° C., silica reverted to tridymite, whilst Day and Shepherd and Brun have also found that in the presence of a "mineraliser" the reversion was effected fairly easily at temperatures between 800° and 1500° C., thus confirming Fenner's statement that silica is converted to tridymite between 800° C. and 1470° C.

Fused silica will not revert to quartz by simple cooling, but in the presence of a "mineraliser" a prolonged heating at a temperature between 300° C. and 750° C. will effect the change; the temperature must not rise above 800° C.

Table XLVI., due to Fenner, shows the changes which silica undergoes when heated and cooled:

TABLE XLVI.—INVERSION OF SILICA

Temperature.	Product.
On heating to about 200° C.	α-quartz (hexagonal tetratohedric).
,, ,, 575° C.	β-quartz (hexagonal hemihedric).
,, ,, 870° C.	β-tridymite (hexagonal).
,, ,, 1470° C.	β-cristobalite (hexagonal).
On cooling, the same products are formed in the reverse order down to 270° C., after which:	
From 270° C. to 180° C.	β-cristobalite changes to α-cristobalite.
,, 120° C. to 115° C.	β-tridymite changes to α-tridymite, and then very slowly into quartz.

The fusibility of a sand depends on the amount of silica and other materials present. Thus, whilst a quartzose sand melts at a temperature between 1500° and 1670° C., a sand containing a large proportion of mica or felspar will melt at a very much lower temperature. Table XLVII. shows the refractoriness of the

principal minerals likely to occur in sand, so that their effect may be roughly estimated according to the amount present:

TABLE XLVII.—FUSIBILITY OF VARIOUS MINERALS

	°C.		°C.
Albite	1135-1215	Haematite	1350-1400
Anorthite	1250-1350	Hornblende	1180-1220
Apatite	1270-1300	Kaolinite	1740
Augite	1145-1150	Labradorite	1245-1250
Barytes	1500	Lepidolite	925-945
Beryl	1410-1430	Magnetite	1190-1250
Calcite	2570	Muscovite	1255-1290
Chalcedony	1500	Nepheline	1180-1210
Chromite	1850	Olivine	1380-1410
Corundum	1750-1800	Orthoclase	1160
Diamond	Infus.	Quartz	1500·
Enstatite	1380-1400	Rutile	1560
Epidote	1250	Sillimanite	1816
Flint	1470	Spinel	1360
Fluorspar	1378	Titanite	1200-1230
Garnet	1150	Tourmaline	1000-1100
Gypsum	1300	Zircon	1900

Owing to its composite nature and the low thermal conductivity of the material, most sand does not melt at a definite temperature as would a pure chemical compound, but passes through a softening stage, which may be more or less prolonged according to the size of the particles and the nature of the materials present. This softening stage is the period intervening between the time when the most fusible constituents begin to melt and the time when the whole mass becomes fluid, and it is increased with large particles, as they require a longer time for the heat to penetrate them than is needed for smaller particles.

The softening stage is also increased by the time required for the inversion of quartz into one or more of the other allotropic forms of silica, which are formed when it is heated.

The temperature differences at which these numerous changes occur vary with each sand; thus, a sand rich in magnesium compounds has a longer softening range than one containing an equivalent proportion of lime. Felspar begins to show signs of fusion at about 1190° C., but is not completely fused below 1300° C., though if other impurities, such as lime compounds, are also present, complete fusion may occur at a temperature of only about 1200° C. Lime alone is almost infusible, but when present in sand it forms fusible compounds, some of which melt at a dull-red heat.

In considering the above table of fusibilities, it must be clearly understood that although a single temperature may be given for a compound likely to occur in sands, this is necessarily

only approximate, for the reason just given, and a *fusion range* would be more accurate than a single *fusion point*. In some cases, fusion may commence at a temperature of only 500° C., but may not be completed until 1200° C. is reached.

When an impure sand is heated, a reaction commences between the sand or siliceous matter and the alkalies, a fusible silicate being formed; the lime next enters into combination and is rapidly followed by the iron. The finer particles of fusible minerals fuse next, and as the volume of fluid increases with the rise in temperature the fluid attacks the larger particles of fusible material, then the coarser particles of quartz, felspar, etc., until only the largest particles of the most heat-resisting materials are left. These are only fused on prolonged heating at a sufficiently high temperature.

The action of various impurities on the refractoriness of silica has been described in Chapter IV. It may be summarised by stating that most of the impurities likely to occur in sands lower the refractoriness to an extent which depends on the nature of the impurity. In large proportions, some minerals such as alumina may increase the refractoriness, but they are seldom present in sufficient quantity to do this, so that it is a fairly safe rule that the most refractory sands are those which consist of pure quartz, and that the presence of any substance other than crystalline silica tends to lower the refractoriness of the sand. According to Richter and Bischof the proportions of various fluxes which effect an equal reduction of the refractoriness are as follows:

Magnesia 20, lime 28, potash 47, soda 31, and red iron oxide 40.

It will be seen that, weight for weight, magnesia is the most active of these materials, and iron oxide has the least effect unless it is reduced to the ferrous state, when it becomes a powerful flux. On comparing these figures with the respective molecular weights, it will be seen that approximately 2 molecules of magnesia are equal in effect to 1 molecule of lime, 1 molecule of potash, 1 molecule of soda, and $\frac{1}{2}$ molecule of red ferric oxide or 1 molecule of ferrous oxide. Hence, with the exception of magnesia (which has not been explained) and of ferric oxide (which is, however, normal under reducing conditions), the effect of the oxides mentioned on the refractoriness of sands containing them is almost exactly proportional to the molecular weight of the oxides. It must be remembered, however, that magnesia is very slow in action and is therefore less dangerous than lime as an impurity. Unfortunately the figures given above by Richter and Bischof are not very reliable, as the relative activity does not depend solely on the proportion of any material present, but is influenced by the presence of other substances. Hence the relative activity of fluxes on quartz is not the same as on a mixture of quartz and clay, or on clay itself, whilst in a mixture rich in silicates, magnesia acts only as a flux up to 5 per cent, after which it has a refractory effect.

It is not at present possible to ascertain, without an actual test, at what temperature a sand will become fluid, as so many factors have to be taken into consideration, including the materials present, their proportions, the sizes of the particles, duration of heating, etc.

Volume Changes on Heating.—The various allotropic changes which occur when silica is heated involve certain changes in volume on account of the difference in the specific gravity of the various forms of silica. These volume changes are often of little importance, but where sands or crushed rocks are used in the manufacture of bricks they may have a serious effect on the expansion of the brickwork, and therefore on the stability of the structure.

At temperatures lower than 100° C. quartz has a coefficient of expansion which is nearly twice as great in a direction perpendicular to its axis as in one parallel to it. When α-quartz is converted into β-quartz at 575° C. there is a change in volume of about 1·4 per cent; on further heating to 870° C. a further increase in volume of 14-16 per cent occurs, the low-temperature forms of silica being formed.

Table XLVIII. shows the volume changes involved in the various allotropic changes of silica:

Table XLVIII.—Changes in Volume of Silica

	Variation in Volume.	
	Inversion.	Reversion.
Quartz $\rightleftarrows$ tridymite	+16 per cent	−14 per cent
Quartz $\rightleftarrows$ cristobalite	+14 ,,	−12 ,,
Quartz $\rightleftarrows$ fused silica	+20 ,,	−17 ,,
Tridymite $\rightleftarrows$ cristobalite	−2·2 ,,	+2·2 ,,
Tridymite $\rightleftarrows$ fused silica	+3·1 ,,	−3·1 ,,
Cristobalite $\rightleftarrows$ fused silica . . .	+5·4 ,,	−5·2 ,,

Besides the volume changes due to the formation of different allotropic varieties of silica, there is also a reversible expansion due to heating and cooling. Quartz expands rapidly up to 550° C. Another very large expansion takes place between 550° and 590° C., this being partly due to the change to an allotropic form, but after heating to 600° C. no further expansion takes place and sometimes a little contraction occurs. On cooling, a very marked contraction occurs, just below 600° C., on account of the reversion of the quartz to the α-state.

...e difference in the coefficient of expansion
.. of silica, the variations being shown in Fig. 17

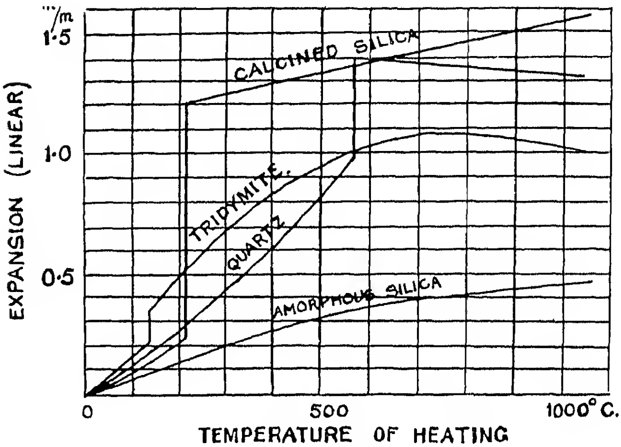


Fig. 17.—Volume changes of silica on heating.

as the results of determinations made by Le Chatelier and Holborn and Henning respectively. The mean coefficient of expansion of silica between 0° C. and 1000° C. is 0·68.

CHAPTER VI

THE EXAMINATION AND TESTING OF SANDS

WHENEVER a material is used which occurs in a natural state it is usually subject to variations in character which may utterly spoil it for the purposes for which it is employed. The sands used in various industries ought, therefore, to be tested in such a manner as to minimise the losses which would otherwise result from the use of unsuitable sand. The necessity for some form of testing is recognised by some users, though some of the " tests " applied are very crude and limited in scope. On the other hand, most users have generally failed to recognise the necessity for more complete knowledge of the sands they employ, and many of them are in consequence paying more dearly for their sands than would be the case if they were purchased as the result of proper tests. A particularly striking example occurred recently in the experience of the author, in which a firm were purchasing sand from 140 miles' distance, when a sand more suitable for their purpose, but of less attractive appearance, could be obtained from a pit close to the works. In this instance a certain amount of prejudice existed, for the foreman was accustomed to a particular sand and did not see fit to change when he entered the employment of another firm. It was only when the characteristics of the two sands were closely compared and their practical identity was proved, that they were used with success on a commercial scale.

The lack of information on the subject of testing makes it difficult to formulate a complete series of tests, and not only do the requirements of different works differ very greatly, but the idiosyncrasies of different workers must also be considered. For instance, in a certain foundry well known to the author, three different moulders used three different sands and could not, for a long time, be persuaded to change. Even that most cruel test of all the secret substitution of one sand for another failed to overcome the difficulty as soon as the substitution was discovered, though during the three months it remained unknown no noteworthy troubles occurred !

Sampling.—In testing sand for any purpose it is of course essential that the sample to be examined should be representative of the whole deposit, or at any rate of that portion of it which is

to be used. Yet only too often is a small portion of the material picked up haphazard and sent for examination regardless of whether it is representative or not. Consequently it frequently happens that a "sample" of so heterogeneous a material as sand gives results which are not and cannot be by any means typical of the material from which it was taken. An examination of such an unrepresentative "sample" is of course useless; in many cases it may be worse than useless, as a material may be unjustly condemned or unfairly favoured as a result of such an examination. The fault in such cases does not lie with the tests, but with those who do not take sufficient care to obtain a proper sample. It cannot be too strongly urged, when a sand is to be examined with a view to determining its value as a commercial commodity, that the sample provided should be sufficiently large and sufficiently carefully chosen to be representative of the whole of the deposit. If it is impossible to obtain a single sample of such a character, a sufficient number of samples should be taken, the number necessarily depending upon the variability of the deposit. By this means it is possible to get a fairly reliable idea as to the nature of any detrital deposit, and the results of an examination will be sufficiently representative.

When testing a deposit or bed of sand, the surface layer should be avoided, as it is liable to serious variation in composition on account of contamination. The best method is to uncover the bed to a convenient depth, and then to cut a vertical face with a spade and from the material so removed to secure a representative sample. To ensure this, a method of "quartering" is commonly used, and when systematically carried out it is quite satisfactory. The principle involved is that if a sufficient quantity of well-mixed material be itself well mixed and a considerable portion of it be removed, this portion again mixed and another portion abstracted, the process being repeated until a sufficiently small quantity has been obtained, the resulting sample will, as far as possible, truly represent the composition of the whole bulk. It is usual to take one-quarter of the mass in each abstraction, but in some cases one-eighth or even one-twelfth will be found to yield accurate results. Thus, if the original material to be examined represents a bulk of about ten tons, it should be mixed as thoroughly as possible, piled into a symmetrical heap, and divided into four quarters. One of these quarters is then removed, again mixed thoroughly, divided into quarters as before, and one quarter again separated. This process is repeated until a "quarter" weighing about 10 lb. is obtained, unless a larger quantity is desired, when the quartering need not proceed so far.

This process is based on the assumption that the material can be thoroughly mixed prior to each quartering. This is only the case where the material consists of small particles; if it is in lumps, these must be broken sufficiently small and, when the bulk has been reduced by quartering, one of the "quarters" must be ground,

roughly quartered again, and the operations of grinding and quartering be repeated until a sample of requisite size is obtained. If the raw material is in the form of a sandstone rock or contains hard pieces of considerable size, it is necessary to grind it so that it will pass completely through a 10-mesh screen before making the last few quarterings, and the chemist who undertakes the analysis or other tests of the material may have to grind the sample still further before he can use it; consequently, he should always be supplied with at least 7 lb. of the sample in the form of a rough powder. If the heap is so large that to take one quarter of it is impracticable, the only other reliable method is to take a large number of samples, each weighing about 4 lb., from many parts of the heap and to mix them thoroughly before quartering as described above. Unless the material is reduced to a fairly fine state of division, the quartering will be inaccurate, as the material cannot be mixed with sufficient accuracy.

The smaller the particles of the material the more accurate will be the result of sampling by quartering, and the more representative will be the sample. Consequently, if no examination is to be made of the sizes of the grains it is usually desirable to grind the material to powder before completing the quartering. Even when it is not desired to grind the sand, it is sometimes advantageous to employ a mechanical mixing machine. Those most usually employed consist of a stationary case in which paddles or blades are fixed on a shaft in an irregular manner, and are so arranged that when the shaft is rotated the blades mix the material thoroughly. Some investigators consider that a small rotary cylinder containing glass marbles or preferably small quartz pebbles gives a better mixing effect, but the possibility of grinding the softer grains and of contaminating the product must not be overlooked.

When it is desired to determine the ferrous oxide in a material the sample should not be ground very fine, as unnecessary grinding causes oxidation of the material by exposing it unduly to air. It is very important that sand should, as far as possible, be tested in its natural condition, and care should be taken that its moisture is not evaporated in transit, as its proportion may be important. Where possible, the sample obtained should be placed at once in air-tight tins or jars, and no undue delay should be incurred before it reaches the testing station.

Phosphor-bronze sieves are generally used to sift the material, but they may introduce metallic impurities.

Chemical Analysis.—The details of the various methods of analysis of sands are of so complicated a nature and require so high a degree of manipulative skill in their execution that they cannot be profitably dealt with here. Readers who wish to experiment in this direction should refer to *A Treatise on Quantitative Inorganic Analysis*, by J. W. Mellor, but they must not be disappointed if, after many attempts, they do not obtain such accurate results

as they require. At the same time it is important that those responsible for the use of sands should be able to understand and make use of the information contained in an analytical report, so that the notes given on pp. 202-203 should be carefully studied. The constituents usually determined in the chemical analysis of a sand are moisture, loss on ignition at about 950° C., silica, titanic oxide, alumina, ferric oxide, lime, magnesia, soda, and potash. Sometimes the percentage of sulphur (as SO_3) and of chlorine are also determined, and in sands which may contain other substances of importance a determination of these constituents should be made. From what has been stated in earlier pages it will be realised that many minerals are decomposed on chemical analysis, and their constituents are reported as silica, alumina, etc. (See also *Mechanical Analysis*, p. 239, and *Rational Analysis*, p. 239.)

Many people who are unable to make an analysis of a sand find it convenient to be able to determine the moisture and loss on ignition.

Moisture.—The amount of moisture in a sand is sometimes very important, especially in moulding sands used for casting metals. To determine the moisture content accurately, a weighing bottle which is fitted with a glass stopper is carefully cleaned, wiped dry, and then dried in a special oven, which is maintained accurately at a temperature of 110° C. by means of a thermostat gas-regulator. When completely dry, the weighing bottle is cooled in a desiccator and then weighed accurately. About 3 gr. of the sample is placed in the bottle, the stopper is replaced in the latter, and the bottle with its contents is re-weighed. The increase in weight gives the weight of sand in the bottle.

The bottle is now taken to the oven, its stopper is removed and placed on a glazed tile on the oven shelf, and the bottle with its contents is placed beside it, the bottle being covered with a small piece of filter-paper to keep any dust from settling into it. The oven door is closed and the oven with its contents is maintained accurately at 110° C. for some time, after which the bottle and contents are cooled as before and re-weighed. The loss in weight will be the weight of moisture in the sample.

To ensure the whole of the moisture having been removed, the bottle is replaced in the oven as before, and after a further period of drying for at least one hour, it is again cooled in a desiccator and re-weighed. If any further loss of weight occurs it shows that the sample has not been fully dried, and the drying, cooling, and re-weighing must be repeated until a constant weight is obtained.

This weight, less that of the bottle and contents previous to drying, is the amount of moisture in the weight of material used.

The record of the results may conveniently be kept in the form shown on the next page.

EXAMPLE:

	Gr.
Weight of bottle and sand	8·6754
Weight of bottle	6·1213
Weight of clay used	2·5541
Weight of bottle and sand before drying	8·6754
Weight of bottle and sand after drying	8·4316
Moisture in weight of sand used	0·2438

Hence 2·5541 gr. sand contain 0·2438 gr. moisture.
∴ Moisture = 9·54 per cent.

Loss on Ignition.—The figure reported as "Loss on Ignition" indicates the weight lost when the sample has been heated to bright redness for several hours. During this heating some minerals (such as clay) are decomposed, and evolve water which escapes as steam and is lost. Any organic matter present will burn away and will also be included in the "loss on ignition." If any finely divided carbonate is present, it may lose some or all of its carbon dioxide. The figure obtained as "loss on ignition" is therefore a composite one, and, though sometimes difficult to interpret, its determination is often useful.

This test may be made by transferring the sample used in the drying test (p. 238) to a small weighed porcelain or platinum crucible and heating it in a small muffle furnace for one hour or so, after which it is allowed to cool in a desiccator and is then weighed. The crucible with its contents should then be reheated for about half an hour, again allowed to cool as before, and reweighed. If any further loss has occurred, the whole of the carbonaceous matter, etc., in the sample has not been removed, and the heating must be continued until a constant weight is obtained. The total loss in weight, expressed as a percentage of the weight of the original sample, is then calculated by multiplying the loss by 100 and dividing by the weight of the sample used in the test.

Mechanical Analysis.—When it is desired to know the proportions of the various sizes of grains present in a sand, a mechanical analysis is made; this is dealt with later under the heading *Grading Tests.*

A mechanical analysis is very valuable for many of the purposes for which sands are used, especially in agriculture, and in the selection of sands for glass-making and for casting metals.

Rational Analysis.—A method commonly known as "rational analysis" is sometimes applied to sands in order to show the proportions of the different minerals present. As these minerals are not definitely identified in a rational analysis, the term is somewhat of a misnomer, and the process is not reliable except under unusual circumstances.

The method of making a rational analysis consists in treating a weighed amount of sand with hot concentrated sulphuric acid for a considerable time. The mixture is then allowed to cool;

it is diluted with water and filtered, the residue being treated several times with boiling solutions of caustic soda and hydrochloric acid. The matter dissolved by this treatment is presumed to be wholly "clay." The residue finally obtained (consisting chiefly of felspar and quartz) is dried and weighed. It is then treated with hydrofluoric acid, which removes the silica, the solution being analysed for alumina, lime, soda, and potash, from which the amount of felspar and quartz may be determined.

The chief objections to and sources of error in this process are: (i.) the whole of the clay present may not be decomposed, though where only a small percentage of clayey matter occurs, as in most sands, there is less risk of incomplete decomposition; (ii.) the decomposed products of the treatment with sulphuric acid may not be entirely removed from the residue, thus increasing the felspar percentage and decreasing the amount of "clay" present; (iii.) some of the felspar and quartz if in a fine state of division may be lost; (iv.) other minerals, apart from clay, may be attacked and partially dissolved, thus increasing the amount of "clay." A greater or less quantity of felspar, hornblende, augite, biotite, andalusite, epidote, and muscovite may thus be included in the amount of clay reported as present (see p. 204); (v.) on account of the heterogeneous nature of the sand, the value obtained for quartz does not represent the amount of free quartz present, but is probably higher than the correct figure; neither does the value for felspar represent the proportion of felspar present, but is rather high, as the other impurities containing silica and alumina are not sufficiently taken into consideration. Hence a rational analysis is only satisfactory in rare cases; where minerals occur in widely different states of division, or where other minerals are present which are attacked to about the same extent as clay and felspar, the results may contain a very large error and in some cases are quite useless.

Re-calculated Analysis.—In many cases, results of more value than those obtained by a rational analysis may be obtained by re-calculating the composition of the sand, as shown by chemical analysis, so as to correspond to certain minerals assumed to be present. Thus, it may be assumed that the alkalies, lime, and magnesia are all in the form of felspar, and the alumina, together with the amount of silica corresponding to this assumed quantity of felspar, is then calculated. Any excess of alumina is next calculated as "clay" of the formula $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, and the silica corresponding to this "clay," together with that corresponding to the felspar, is deducted from the total silica; the remaining silica is then assumed to be free quartz.

In some sands the percentage of iron compounds is so large that it requires special consideration. As the most abundant iron compound in sands is limonite—a hydrated ferric hydroxide of somewhat variable composition (p. 189)—it is sometimes convenient and usually fairly accurate to calculate the iron oxide found by

chemical analysis to limonite, $2Fe_2O_3 . 3H_2O$. If an appreciable percentage of ferrous oxide is present it may be assumed to exist as $FeO . H_2O$.

This method gives results which are often instructive, but they are subject to the serious objection that felspars do not contain magnesia and that in some sands the bases are present in the form of mica and other minerals.

Proximate Analysis.—The purpose of a proximate analysis is to state the proportions of various minerals actually present in the sand, as distinct from the results shown by chemical analysis. In the latter, the silica from the various minerals is included in a single figure, so that a chemical analysis often fails to show the nature and percentage of the impurities present. For example, a sand composed of 90 per cent of quartz and 10 per cent of pure clay will contain 94·6 per cent of silica, 3·9 per cent of alumina, and 1·5 per cent of water (loss on ignition). It might be supposed that as there is 94·6 per cent of silica there could only be 5·4 per cent of impurities, but this is not the case, for 4·6 per cent of the silica forms part of the "impurities" and the total impurity amounts to 10 per cent. Similarly, a sand consisting of 90 per cent of quartz and 10 per cent of (orthoclase) felspar will show on analysis 96·5 per cent of silica, 1·8 per cent of alumina, and 1·7 per cent of potash, but the impurity will not be 3·5 per cent (the figure obtained by deducting the silica from 100) but 10 per cent, as part of the silica belongs to the felspar.

In most sands the conditions are much more complex, so that it is usually difficult, and often almost impossible, to ascertain accurately their proximate composition. Four methods are available:

1. A mechanical analysis (p. 239), which will separate some of the minerals from the remainder.

2. A rational analysis (p. 239), which is, unfortunately, seldom reliable.

3. A re-calculated analysis, which is only of use when the composition of the sand is comparatively simple, and even then is liable to be misleading (p. 240).

4. A microscopical examination of the material as a whole, or of each of the grades into which it can be separated by mechanical analysis (*see below*).

These methods, in conjunction with a chemical analysis of the material as a whole, or still better with a separate chemical analysis of each of the more important grades separated by mechanical analysis, or of the pieces picked out by the aid of a microscope, will give a sufficiently accurate idea of the approximate composition of the material to serve all practical purposes.

If necessary, these methods are supplemented by special tests and by the use of methods of separation applicable to particular minerals.

Microscopical Analysis.—A systematic examination of a sand

under a microscope will give a good idea of the various minerals present and, roughly, the proportion of each, and the results of such an examination are often more accurate than those obtained by any other single method. The microscope is particularly valuable in identifying certain minerals, and it is the only means at present available of estimating the amount of cristobalite, tridymite, etc., in some heated silica rocks.

The microscopic examination requires the use of a good microscope magnifying up to about 500 diameters (higher powers are seldom necessary), fitted with polarising apparatus, so that the characteristics of minerals in polarised light may be examined. It is usually better to examine the various grades separated by mechanical analysis than to confine the examination to an indiscriminate sample of the whole bulk.

If the sample has to be treated with water, in separating the particles of various sizes any dust will have been removed from the bulk of the material ; otherwise, the sample should be stirred up with water and the water and the finest particles in suspension should be poured off, or they may cause trouble by masking the grains. These minute particles should be examined separately and not overlooked, as is frequently the case.

The particles are placed on a suitable glass slide, and, if necessary, cemented by balsam or immersed in oil of cloves or other suitable medium. They should then be examined first in natural and afterwards in polarised light, so as to ascertain the proportions and the various characteristics of the different minerals present. The identification of the various minerals present requires a certain amount of skill and knowledge of the particular characteristics possessed by different minerals, but after sufficient experience has been gained, the commoner minerals may readily be identified. To facilitate the examination, the sample should be separated into grades by means of (*a*) sieves (p. 246) and (*b*) heavy liquids (p. 257), as the minute, amorphous particles of clay, etc., are in this way prevented from obscuring the other grains. The heavy minerals also enable the quartz—which constitutes the greater part of the sand—to be separated, and the minerals of greater specific gravity than quartz are obtained in a highly concentrated form and so can be easily examined.

The various characteristics which should be observed include the shape and crystalline form of the grains, cleavage, fracture, enclosures, alteration, refractive index, pleochroism, birefringence, extinction angle, interference figures, twinning, etc. The more important of these characteristics are described in Chapter IV., and from what is therein stated it is usually possible to identify all the common minerals. The characteristic properties of minerals which are difficult to determine have been omitted from this volume, as they are only seldom required. Further information thereon will be found in the leading text-books on mineralogy and petrology.

One of the most important characteristics which can be determined microscopically is the refractive index. This is determined by the use of various liquids of known refractive index. The liquids used must be carefully tested by means of a refractometer before use, so as to be sure that they are according to standard. Table XLIX., due to Schroeder van der Kolk, shows the refractive index of certain liquids:

TABLE XLIX.—REFRACTIVE INDICES

Material.	Refractive Index.	Material.	Refractive Index.
Ethylene chloride	1·450	Monobrombenzol	1·561
Olive oil	1·469	Orthotoluidine	1·571
Benzol	1·501	Aniline	1·583
Cedarwood oil	1·505	Bromoform	1·590
Monochlorbenzol	1·523	Cinnamon oil	1·605
Ethylene bromide	1·536	Moniodobenzol	1·619
Clove oil	1·544	a-Monochlornaphthalene	1·635
Nitrotoluol	1·546	a-Monobromnaphthalene	1·655
Nitrobenzol	1·552	Methylene iodide	1·740
Dimethylamine	1·558	Sulphur in methylene iodide	1·839

Another useful method is that described by A. B. Dick (p. 178). When a mineral is immersed in one of the above-mentioned liquids, it will be found that if the refractive indices of the liquid and the mineral are very nearly equal the mineral will be practically invisible, whereas if there is an appreciable difference between the refractive indices the mineral will be easily seen. Under the microscope, if there is a large difference between their respective refractive indices the fragments of mineral will appear to have thick borders.

In order to determine whether the refractive index of the mineral is higher or lower than that of the liquid, the light should be cut off from a portion of the field by tilting the microscope mirror, so as to cause the minerals to be dark on one edge and light on the other. The position of the dark edge should be noted, and if it lies on the opposite side of the grain to the shadow the grain has a lower refractive index than the liquid, whilst if it is nearest to the shadow the mineral has a higher refractive index than the liquid.

Another method suggested by Becke consists in raising the objective lens of the microscope until the grain is out of focus. Whilst this is being done a bright line will move from the material having the lower refractive index to the one having the higher value. If the objective is lowered instead of raised the reverse action takes place. By repeating one of these tests with a series of different liquids it is easy to determine which liquid has a refractive

index nearest to that of the mineral. The refractive index of the liquid may then be determined in a refractometer.

If the material to be examined is in the form of a piece of rock it may be rubbed down so as to have one smooth surface which can be examined by reflected light. Afterwards it may be ground so as to form a thin transparent section about 0·001 in. thick, which is then mounted in Canada balsam on a glass slide and covered with a thin cover of glass. The slide can then be examined by transmitted light, the same optical tests being applied as for sands.

Other sections may be further investigated by staining or etching. The slide is made as before, but without Canada balsam, and its surface treated with dilute hydrochloric acid to ascertain whether any carbonates or alkali silicates, such as lime-scapolite, nepheline, sodalite, melilite, hauyne, nosean, lazurite, anorthite, olivine, chlorite, serpentine, and zeolites, are present, as these are gelatinised by this acid. Felspar and quartz are gelatinised only by hydrofluoric acid. To stain the section, the acid is washed away with water and afterwards with ammonia, and the sample then placed in a bath of stain, such as magenta, malachite green, Congo red, aniline blue, or methylene blue. After a sufficient time has elapsed to permit the sample to be completely stained, it is removed, washed, dried, and examined under the microscope. This method is sometimes useful in showing up certain minerals more than others.

Other special tests are sometimes useful though seldom required. Further information as to these tests will be found in the text-books on mineralogy and petrology.

Cleanness.—The " cleanness " of a sand may be tested roughly by rubbing it between the fingers ; a good clean sand will leave little or no discoloration on the fingers. A perfectly clean sand may be rubbed on white paper without leaving any dark marks. Another very useful though rough test of the cleanness of a sand consists in shaking some of it violently for a few minutes in a measuring glass half-filled with water. After shaking, the sand is allowed to settle, and the other material will gradually sink and form a layer on the top of the sand. The amount of dirt, etc., can be roughly determined by noting the number of divisions of the measuring glass which correspond to the thickness of the layer of dirt, and by estimating the amount of matter in suspension. This test is useful in determining whether a sand for use in making mortar or concrete needs to be washed before use.

A better test consists in stirring up a weighed quantity of sand with several times its weight of water, pouring off the liquid through a 100-mesh sieve, and repeating the treatment with water until no more " dirt " remains in the residual sand. The liquid and " dirt " which have passed through the sieve are then evaporated to dryness, and the product is weighed and calculated as a percentage. As the fine sand consists of silt, clay, and organic (carbonaceous) matter, this residue may be ignited so as to drive off the car-

bonaceous matter, allowed to cool, and then re-weighed. The loss in weight may be regarded as representing the organic matter, together with any water produced by igniting the clay and other hydrous minerals present. (See also *Carbonaceous Matter*, p. 246.)

Colloid Matter.—A rough idea of the amount of colloidal matter (*clay*) in a sand may be gained by shaking up the sand with twenty times its weight in water in a tall glass cylinder, and noting the amount of matter remaining in suspension after one minute (p. 244). The test is vitiated by the extremely fine sand present, some of which may remain in suspension for several hours. A much more satisfactory method of separating the clay from the other constituents in a sand is to use a series of sieves and an elutriator (see p. 246).

Another useful method of comparing the amount of clay in batches of moulding sand is the following modification of a method proposed by Ashley:

0·75 gram of aniline green (malachite green) is dissolved in 250 c.c. of water and shaken for five minutes. Fifty grams of the sand are added and the liquid is shaken in a machine for ten minutes, after which it is poured into a settling bottle and allowed to stand overnight. The colour of the liquid is then compared with a standard solution of 0·75 gram of dye in 250 c.c. of water which has been shaken and allowed to stand in the same way. A sand containing clay abstracts some of the dye from the liquid, the extent of the decolorisation being to some extent a measure of the amount of clay present. The best method of determining the extent of decolorisation is to dilute the standard solution to the same extent as the sample, and to take the extent of dilution as a measure of the amount of clay present. This method is very useful for comparing different batches of sand from the same source, but it has been found unsuitable for comparing widely different sands, on account of the variation in the absorbing power possessed by different clays.

H. B. Hanley and H. R. Simonds have obtained better results by treating the sand prior to adding it to the dye-solution. They suggest placing 25 grams of the sand in a 500-c.c. wide-mouthed bottle, and adding 250 c.c. of distilled water, and 5 c.c. of 10 per cent ammonium hydroxide. The bottle is closed with a glass stopper and sealed with paraffin wax, and is placed in a shaking machine for one hour. At the end of this period, 140 c.c. of distilled water is added, together with sufficient acetic acid to neutralise the ammonia and leave an excess of acid. This usually requires 5 c.c. of 10 per cent acid. This treatment cleans the surface of each microscopic particle, and ensures that the colloidal matter is in a state to attract or absorb the dye. The test may be continued by adding a weighed quantity of the dye crystals to the solution and sand, sufficient dye being added so that, after stirring and allowing the sand to settle, a slight tinge of colour remains in the solution. This indicates that a slight excess of the dye has been added; its amount is estimated by preparing a standard solution

. diluting it until it has the same colour as the liquid ıe test. The quantity of dye in the diluted solution , that amount is deducted from the total weight of ..sed. This is regarded as proportional to the colloidal .sent.

bonaceous matter, which is objectionable in sand to be ı concrete, may be estimated by means of a simple test ted by Abrams and Harder, and since adopted as a "clean- test by the American Society for Testing Materials, who ...mend that it should be carried out as follows:

A 12-oz. graduated prescription bottle is filled to the $4\frac{1}{2}$-oz. ark with the sand to be tested. A 3 per cent solution of sodium ydroxide is then added until the volume of the sand and solution, after shaking, amounts to 7 oz. The bottle is then closed by a cork or stopper and shaken thoroughly, after which it is allowed to stand overnight. The next day the colour of the more or less clear supernatant liquid is observed; if it is colourless or has a light yellow colour, the sand may be considered to be satisfactory in so far as organic impurities are concerned. If, on the other hand, a dark-coloured liquid, ranging from dark red to black, is obtained, the sand should usually be rejected as unsuitable for use in concrete or mortar.

Grading Tests.—The separation of a sample of sand into groups according to the sizes of the constituent grains of material present is known as "grading"; a determination of the proportion of each grade is termed a mechanical analysis, and consists in treating the material present either by means of sieves, or in an elutriator, so as to separate the particles of one size (or those within certain prearranged limits of size) from the remainder. By repeating the process a sample is eventually subdivided into a considerable number of separate grades; the weight of each can then be ascertained. To separate the coarser grains of sands, sieves are the most satisfactory, it being generally best to select a number of sieves of decreasing fineness, according to the grades into which it is desired to separate the particles.

In order to obtain strictly comparable results it is important to use standard sieves, as ordinary ones are not woven with sufficient accuracy.

Table L. shows the standard meshes of sieves specified by the Institute of Mining and Metallurgy.

The sieves are manufactured by N. Greening & Son, of Warrington.

[TABLE

Table L.—The I.M.M. Standard Sieves [1]

Mesh, *i.e.* Apertures per Linear Inch.	Diameter of Wires.		Diameter of Apertures.		Screening Area per cent. Holes.
	in.	mm.	in.	mm.	
5	0·1	2·540	0·1	2·540	25·00
8	0·063	1·063	0·062	1·574	24·60
10	0·05	1·270	0·05	1·270	25·00
12	0·0417	1·059	0·0416	1·056	24·92
16	0·0313	0·795	0·0312	0·792	24·92
20	0·025	0·635	0·025	0·635	25·00
30	0·0167	0·424	0·0166	0·421	24·80
40	0·0125	0·317	0·0125	0·317	25·00
50	0·01	0·254	0·01	0·254	25·00
60	0·0083	0·211	0·0083	0·211	25·00
70	0·0071	0·180	0·0071	0·180	25·00
80	0·0063	0·160	0·0062	0·157	24·60
90	0·0055	0·139	0·0055	0·139	24·50
100	0·005	0·127	0·005	0·127	25·00
120	0·0041	0·104	0·0042	0·107	25·40
140	0·0036	0·091	0·0036	0·091	25·00
150	0·0033	0·084	0·0033	0·084	24·50
160	0·0031	0·078	0·0031	0·078	25·00
180	0·0028	0·071	0·0028	0·071	25·00
200	0·0025	0·063	0·0025	0·063	25·00

[1] Some additional data by J. W. Mellor have also been included in the table.

Table LI. shows the standards adopted by the American Bureau of Standards.

F. W. Taylor has suggested the sieves given in Table LII. for testing the grading of sands for concrete work.

This series of sieves is based on the following complex considerations: the limiting diameters of the particles in each grade were first decided and also the number of grades into which the material is to be separated. The logarithms of the extreme diameters of the particles were then found, and between these figures was found the required number of logarithms, less 2, which have equal differences between them. By this means a series of logarithms was found equal to the number of sieves to be used, the difference between each succeeding logarithm being constant. The corresponding antilogarithms furnish the openings for each sieve in the series, and where these do not correspond to a commercially available sieve, the nearest commercial sieve is employed. So elaborate a procedure is seldom adopted, and the I.M.M. series (*above*) is ample for most purposes, especially as a sieve in ordinary use does not pass every grain smaller than its holes or "mesh," though it does retain all those which are larger. If the sieving process is of very short duration, a large proportion of fine material will fail to pass through the screen; if the process is excessively prolonged, some of the larger particles may be reduced by attrition

TABLE LI.—AMERICAN STANDARD SIEVES

	Opening.		Wire Diameter.		Tolerance in Average Opening.	Tolerance in Wire	Tolerance in Maximum	Meshes per cm.	Meshes per in.
	mm.	in.	mm.	in.	per cent.	per cent.	per cent.		
	8·00	0·315	1·85	0·073	1	5	10	1	2·6
	6·72	0·265	1·65	0·065	1	5	10	1·2	3·0
3½	5·66	0·223	1·45	0·057	1	5	10	1·4	3·6
4	4·76	0·187	1·27	0·050	1	5	10	1·7	4·2
5	4·00	0·157	1·12	0·044	1	5	10	2	5·0
6	3·36	0·132	1·02	0·040	1	5	10	2·3	5·8
7	2·83	0·111	0·92	0·036	1	5	10	2·7	6·8
8	2·38	0·094	0·84	0·033	2	5	10	3	7·9
10	2·00	0·079	0·76	0·030	2	5	10	3·5	9·2
12	1·68	0·066	0·69	0·027	2	5	10	4	10·8
14	1·41	0·0557	0·61	0·024	2	5	10	5	12·5
16	1·19	0·0468	0·54	0·021	2	5	10	6	14·7
18	1·00	0·0394	0·48	0·0187	2	5	10	7	17·2
20	0·84	0·0331	0·42	0·0165	3	5	25	8	20·2
25	0·71	0·0278	0·37	0·0146	3	5	25	9	23·6
30	0·69	0·0234	0·33	0·0129	3	5	25	11	27·5
35	0·50	0·0197	0·29	0·0113	3	5	25	13	32·3
40	0·42	0·0166	0·25	0·0098	3	5	25	15	37·9
45	0·35	0·0139	0·22	0·0085	3	5	25	18	44·7
50	0·30	0·0117	0·188	0·0074	4	10	40	20	52·4
60	0·25	0·0098	0·162	0·0064	4	10	40	24	61·7
70	0·21	0·0083	0·140	0·0055	4	10	40	29	72·5
80	0·177	0·0070	0·119	0·0047	4	10	40	34	85·5
100	0·149	0·0059	0·102	0·0040	4	10	40	40	101
120	0·125	0·0049	0·086	0·0034	4	10	40	47	120
140	0·105	0·0041	0·074	0·0029	5	15	60	56	143
170	0·088	0·0035	0·063	0·0025	5	15	60	66	167
200	0·074	0·0029	0·053	0·0021	5	15	60	79	200
230	0·062	0·0025	0·046	0·0018	5	15	60	93	233
270	0·053	0·0021	0·041	0·0016	5	15	60	106	270
325	0·044	0·0017	0·036	0·0014	5	15	60	125	323

TABLE LII.—SIEVES FOR TESTING THE GRADING OF SANDS FOR CONCRETE

Sieve No.	Opening in inches.
10	0·073
15	0·047
20	0·034
30	0·022
40	0·015
60	0·009
74	0·0078
100	0·0045
150	0·00325
200	0·00275

and so pass through the screen. With care, the proportion of fine material which fails to pass the screen should not exceed 2 per cent. The tailings from each screen should be tested periodically to ensure that they do not contain too much fine material.

The sieves selected should depend, of course, on the nature of the sand, but in most cases sieves ranging from about 30-mesh to 120-mesh are sufficient, though a 200-mesh sieve may be necessary in some cases. For testing sands the author has for more than twenty years used a series of sieves with 10, 25, 50, 100, and 200 holes per linear inch, the respective apertures being 0·05, 0·02, 0·01, 0·005, and 0·0025 in. in diameter. Boswell prefers to use a series of sieves with 6, 12, 25, 50, and 120 holes per linear inch for the sand grades. From the variations in the series of sieves used by different authorities, it will be understood that the sizes into which the sands are classified depend largely on the requirements of the worker, but where possible it is desirable to adopt some standard classification such as those mentioned on pp. 210 to 216, so as to avoid confusion and to make the results as comparable as possible. Grading tests made with sieves without stating the size of the grains indicated by the various sieves employed, are of no value except to the user.

Some investigators employ a needless number of sieves in a series. The proper course is to ascertain, from a microscopic examination of a limited number of grades, whether the particles in each are sufficiently uniform in size. If not, an additional number of sieves should be employed. Except in unusual cases, however, it is preferable to classify into the minimum number of grades possible, as the mere multiplication of grades is of little value. Whatever series is employed, it is usually desirable, for the sake of consistency and rapid working, to use woven sieves of phosphor-bronze throughout the series, though for removing particles larger than 0·2 in. diameter, and especially when stones or gravel are abundant, perforated sheets are preferable to woven mesh. It is useless to attempt to employ sieves finer than 250-mesh, and, for most purposes, it is better to regard a 200-mesh as the finest practicable sieve, and to use an elutriator for grading the particles which pass through this sieve.

The *manner of using sieves* is important. If the sand is clean (*i.e.* almost free from clay) and dry, a weighed amount may be sieved in its natural state, care being taken to avoid the loss of any "dust." On the contrary, if there is an appreciable proportion of clay present, the weighed amount of sand is mixed with about twice its weight of water, well shaken for half an hour or more in a mechanical agitator, and then run on to the coarsest sieve; any material which passes through the sieve is received in a suitable vessel, preferably of white earthenware, and is afterwards passed in a similar manner on to each of the sieves in turn. Each sieve is then washed with a powerful "rose" of water, so as to ensure all the sand finer than its mesh passing on to the next finer

sieve. When all the finer particles have been removed from each grade, the contents of the various sieves are dried and weighed. The material which passes through the finest sieve contains all the clay, together with a considerable proportion of fine sand and silt. The constituents of this mixture may, if desired, be separated by elutriation (p. 252). The thoroughness with which the fine particles are removed from the residue on the various sieves depends largely on the operator. To reduce the effect of this "personal factor," some investigators work to a strict time-schedule; others prefer to use a mechanical agitator and to rely on this rather than on hand-sieving. The mechanical arrangement is chiefly used in the United States; it consists of a series of sieves mounted one above another, with a container below and a cover above, so as to prevent the escape of dust. A prearranged weight (usually 100 grams) of the sand (previously dried at 110° C. to a constant weight) is placed on the top sieve, and the whole series is then shaken for exactly five minutes by means of a ¼-h.p. electric motor. Each sieve is then removed and shaken separately by hand for one minute more, and any material which passes through is transferred to the next sieve in the series. The whole of the series of sieves with their contents is again assembled, with the container and cover, and is shaken again by the machine for a period of twenty minutes, after which, each sieve in turn is again shaken by hand as before. The amount eventually remaining on each sieve is separately weighed, the results being expressed as the percentage retained on each sieve. No standard method of sieving with the aid of water has yet been adopted.

The deposits left on the coarser sieves generally consist of quartz and felspar. Mica is generally concentrated on the medium sieves on account of its flaky nature, the diameter of the flakes being large compared with the average bulk of other minerals (see p. 217), and the deposits on the finer sieves contain the greater part of the heavier minerals, as the grains of these are generally smaller than the average size of the quartz grains (p. 216).

Sedimentation and Elutriation.—For the finest particles contained in sands, sifting is useless, as sieves finer than 200-mesh, *i.e.* for particles 0·0025 in. diameter, are not sufficiently accurate, as the strands are liable to be rapidly destroyed on account of their fineness and delicacy. It is, therefore, preferable to separate these fine particles by treating them with water in such a manner that they are separated according to their suspensibility. This may be done in one of two ways.

Sedimentation Method.—The particles may be stirred with water until all are in suspension and they may then be allowed to settle. They will sink towards the bottom of the vessel in which they are contained, at a rate which depends on their diameters and specific gravity, in accordance with Stokes' law.

$$V = \frac{2D - d}{9z},$$

or $$V = Cr^2, \text{ where } C = \frac{2(D-d)g}{9z},$$

where V is the velocity of the particles in cm. per sec.,
z is the viscosity of the liquid (water = 1),
r is the radius of the particles in cm.,
g is 981,
d is the specific gravity of the liquid,
D is the specific gravity of the particles.

This formula assumes that (*a*) the particles of solid matter are much larger than the particles of the liquid; (*b*) the liquid is of infinite length in comparison to the sinking particles; (*c*) the particles are smooth and rigid; (*d*) no slipping occurs between the particles of the liquid; (*e*) the velocity is small; and (*f*) the particles are small. When the velocity of the particles is great, the formula does not hold. H. S. Allen states that the maximum size of particle for water sedimentation is 0·085 mm. or 0·0034 in., *i.e.* the particles should all pass completely through a standard sieve (p. 247) of 150-mesh. Rittinger gives the following velocities of fall in metres for particles of different sizes:

3·2 C. for rounded grains,
2·25 C. for flat grains,
2·65 C. for elongated grains,
2·85 C. for average (mixed) grains,

where $$C = d\frac{(S-s)}{s},$$

when S = Specific gravity of solid particles (quartz = 2·65),
s = Specific gravity of liquid (water = 1),
d = Diameter of sphere in metres.

For convenience it is usually assumed that all the particles have the same specific gravity, namely, that of quartz 2·65, in which case the rate of settling depends solely on the diameter of the particles. If a cylindrical vessel 6 in. or more in height is used, and the total height of the liquid and solid in the vessel is greater than 4 in., Table LIII. may be used, the depth of liquid being measured downwards from the *top*.

TABLE LIII.—SHOWING SIZE OF PARTICLES WHICH SETTLE OUT IN DIFFERENT TIMES

Size of Particles.		Time of Settling.	Depth from Surface.	
mm.	in.		mm.	in.
0·1	0·004	20 secs.	140	5·6
0·05	0·002	1 min.	120	4·8
0·01	0·0004	10 ,,	90	3·6

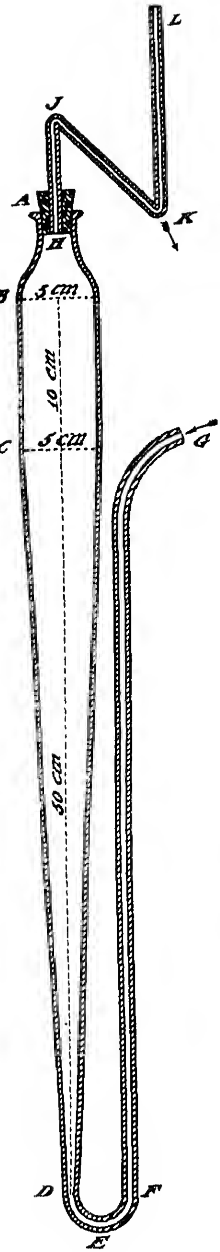


FIG. 18.—Schoene's elutriator.

After standing for ten minutes, the uppermost 3·6 in. of the liquid is carefully siphoned or poured off, care being taken not to disturb the material at a greater depth. The residue left in the vessel will contain all the particles larger than 0·0004 in. diameter. The residue, together with sufficient water to make the total volume the same as before, is well stirred, and then allowed to stand for a further period of one minute. The uppermost 4·8 in. are removed as before; the residue will contain all the particles larger than those corresponding to the period of sedimentation, *i.e.* larger than 0·002 in. diameter. By repeating the process as often as is desired, the particles can be separated into any required number of sizes or grades. The separation of the different sizes of non-plastic materials is usually quite sharp, but when much clay is present it is usually necessary to repeat the treatment of each fraction several times, and even then a small but variable proportion of fine sand and silt usually adheres to and is carried away with the clay, whilst another equally variable amount of clay is usually carried down by the silt and fine sand. It is impossible to prevent this defect unless the particles can be kept well separated and in constant motion. Moreover, as a result of the short times of suspension, and the time necessarily taken in decanting or pouring off the supernatant liquid, the results obtained by sedimentation are not so satisfactory as by elutriation, though they are often sufficiently accurate for general use. Consequently, elutriation is usually preferable to sedimentation.

Elutriation consists in mixing the particles to be separated with a large volume of water which flows forward at a prearranged rate, so as to carry away the smaller particles and leave the larger ones behind. The method most commonly used in this country is that devised by Schoene and modified by Seger, in which a carefully regulated stream of water is passed through a series of vessels, such as that shown in Fig. 18, so arranged that the speed of the liquid may effect a separation of the particles into separate groups. Separa-

tion by elutriation appears to be accurate for particles less than 0·25 mm. (0·01 in.), but not for those larger than 0·5 mm. (0·02 in.), this upper limit being somewhat doubtful. Seger adopted four groups for elutriation, as shown in Table LIV.

TABLE LIV.—ELUTRIATION (Seger's Figures)

Maximum Velocity.		Extreme Diameter of Spherical Particles.		Manometer Height.	
mm. per sec.	in. per min.	mm.	in.	cm.	in.
0·18	0·43	Below 0·01	Below 0·0004	1	0·4
0·70	1·68	0·01 -0·025	0·0004-0·001	8	3·15
1·50	3·60	0·025-0·04	0·001 -0·0016	50	19·69
Residue	Residue	0·04 -0·333	0·0016-0·0133	..	..

It is not necessary, in most cases, to use an elutriator for such coarse particles as those of 0·333 mm. diameter, and often it is quite sufficient to separate only one grade by elutriation, as shown in Table LV., due to Mellor.

TABLE LV.—ELUTRIATION (Mellor's Figures)

Maximum Velocity.	Manometer Height for Flint.	Extreme Diameter, Spherical Particles.	Average Diameter.
mm. per sec.	cm.	mm.	mm.
0·18	1	Below 0·01	0·0063
0·3 or 200-sieve	60	0·01 -0·063	0·042
120-sieve	..	0·063-0·107	0·087

Boswell, using a modification of Crook's elutriator, employs the data in Table LVI.

TABLE LVI. ELUTRIATION (Boswell's Figures)

Diameter of Cylinder.	Head of Water.	Jet Aperture.	Diameter of Grains Separated.
		mm.	mm.
2 in. (51 mm.)	1880	7	0·4
,, ,,	1400	3	0·2
3 in. (76 mm.)	700	3	0·1
,, ,,	400	2	0·05

..e of glass are fragile, so that where a large to be done the more substantial apparatus and shown in Fig. 19, may be used. It consists ...c containers of varying diameters, and to which ..red from a tank at a constant speed. The diameter ... container determines the speed of the column of water so that the speed will be greatest in the narrowest, and least widest container. By this means, particles of various sizes be readily separated. As the volume of water in Krehbiel's apparatus is much greater, and other difficulties are caused by

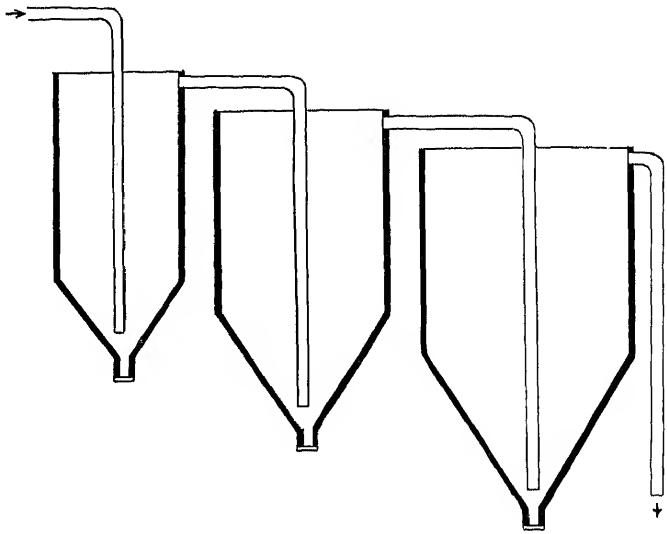


FIG. 19.—Krehbiel's elutriator.

the different shape of the vessels, the results are not so accurate as those obtained with Schoene's or Crook's elutriators.

An elutriator for rapid working, devised by T. M. Lowry, consists of a vertical tube, tapering from 25 mm. to 2 mm., and cemented at the lower end to a 2-mm. tube about 100 mm. long, and fitted with a tap. Elutriation is carried out in the usual way (p. 252), and after about thirty minutes the coarse material is allowed to settle, the height of the deposited column being a measure of the amount of coarse material in the sample under test.

The separation of the finest grains by elutriation may be complicated by their tendency to flocculate; this is especially the case with particles of clay and silt less than 0·01 mm. diameter, though in most cases it is quite unnecessary to separate particles finer than this. Such flocculation may sometimes be avoided by adding a little sodium carbonate or ammonia to the water

used in the test, but such an addition is open to the objection that it may exert a deflocculating action and break up particles of naturally flocculated matter.

The experimental results obtained by elutriation do not agree closely with the theoretical results, on account of numerous "variables" which cannot be considered. Thus, the temperature of the water affects its capacity for suspension, cold water being able to suspend or transport larger particles than warm water travelling at the same velocity. A temperature of 15° C. is usually taken as standard. The amount of material in suspension in a given volume of water must also be taken into consideration, as a few isolated grains may be moved by a current of less velocity than a larger number of grains of the same size, so a greater speed is required to move grains of a given size where the concentration is greater. For this reason, the speeds shown in Table LVI. are a little higher than the theoretical figures. The specific gravity and the shape of the particles also affect their suspension, though the variations in this respect are not so great as might be supposed, because the particles of the heavier minerals are smaller than the quartz grains of the same weight, so that the product carried over by any given speed of flow may contain heavy grains of smaller diameter and mica flakes of larger diameter than is anticipated.

The results obtained are not strictly comparable to those obtained by sifting, as in elutriation the particles present to the current the greatest possible area, whereas in screens the lowest cross-sectional area determines whether a given particle will pass away.

Particles of various sizes may also be separated in a centrifugal separator, through which there is a constant downward flow of water, provided the drum or cylinder of the separator is relatively long in proportion to its diameter. If such a machine rotates sufficiently rapidly, and water containing the solid matter in suspension is fed slowly into the top of it, preferably on to a horizontal disc, which throws it out on to the periphery, the liquid will form a hollow cylinder which moves slowly downward through the separator drum in a spiral direction, until it eventually passes out through the apertures in the lower end of the drum. Meanwhile, centrifugal force causes the particles in suspension to travel radially outwards until they reach the inner surface of the separator, to which they adhere. As the coarsest particles will reach the surface of the separator first, and the others at later intervals, dependent on their size and specific gravity, it will be found, after passing a suitable quantity of material through the separator, that the suspended particles have all been removed from the liquid, and have been arranged in series on the interior of the separator. If the separator is fitted with a loose lining, consisting of a number of segments, these can be so arranged that each pair of segments contains particles of a definite size. The water flowing from the separator is quite clear if the separation has been properly effected,

:lay and silt are not required, a
ıachine will enable them to be

water used by this method is much less than
.. ıd the results appear to be quite satisfactory
ae rotation, the amount of the material and water,
.. which they are supplied are kept constant.

...gical Examination.—For many purposes it is important .. ...certain what minerals are present in a sand and, where practicable, the approximate proportion of each mineral. This can be done to a large extent by means of chemical and mechanical analysis, aided by a microscopic examination (p. 241), but in some instances other methods are preferable. The most important of these are—

1. Separation by vibration.
2. Panning or hydraulic separation.
3. Separation by heavy liquids.
4. Magnetic or electromagnetic separation.
5. Electrostatic separation.

Separation by Vibration.—A method of separating heavy from light minerals in sands of nearly uniform size, suggested by H. B. Milner, consists in placing them upon a piece of white glazed paper, and giving the paper a circular motion with one hand and tapping it with a pencil in the other, at a frequency ascertained by trial. This gives a good separation if small quantities are taken.

An improved method consists in using a thin metal plate supported by an iron clamp and vibrated rapidly, the result desired being obtained by means of a tuning-fork of the same frequency as the metal plate.

Panning is the old method employed for working metalliferous sands and is dependent on the fact that, if water containing sand is placed on a shallow pan (Fig. 20), and given a circulatory motion by means of the arms, the lighter particles are kept in suspension and gradually washed over the sides of the pan, whilst the heavy minerals remain at the bottom. A very convenient pan is one about 3 in. deep and 12 in. diameter at the top and about 8 in. diameter at the bottom. In some cases a conical vessel is employed, and is even more satisfactory than one with a flat bottom, though more difficult to manipulate. With either of these vessels 4-7 lb. of material may be treated at once, and most of the grains having a specific gravity greater than 3 can be retained, all those of lower specific gravity, including the quartz, being almost wholly removed. This method is suitable for particles between 0·004 and 0·04 in.

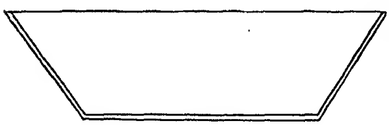


FIG. 20.—Washing-pan.

diameter; with larger particles the separation is less complete, though if they are only present in small proportions they do not seriously interfere with the result. Particles less than 0·004 in. diameter are usually lost by this treatment unless they have a very high specific gravity, such as gold. On the whole, panning is a very satisfactory method for concentrating the heavy minerals in a sand consisting chiefly of lighter material. It has the great advantage of not requiring any elaborate apparatus, and so is invaluable to prospectors in out-of-the-way places.

Separation by Heavy Liquids.—Minerals may also be separated according to their specific gravities by the use of liquids of different specific gravity. Table LVII. shows the specific gravity of various heavy liquids which are useful for this purpose. If a weighed quantity of sand is introduced in small quantities at a time into one of these liquids contained in a conical glass funnel, provided with a tap or stop-cock at its lower end, stirred vigorously and then allowed to stand, all the particles having a lesser specific gravity than the liquid will remain in suspension, whilst the heavier materials (*i.e.* those of greater specific gravity than the liquid) will sink to the bottom of the vessel. The tap is then opened and the heavy minerals run off on to filter paper, after which the tap is closed and more material put into the funnel until the whole has been separated into two parts. The residue can be cleaned with benzene or water, dried rapidly, and weighed. Thus, heavy minerals can be separated from quartz by means of bromoform, and, if necessary, they can be further classified by the subsequent use of other heavy liquids.

TABLE LVII.—SPECIFIC GRAVITIES OF HEAVY LIQUIDS

Liquid.	Specific Gravity.	Melting Point.	How Used.
Bromoform	2·85		Diluted with benzene.
Acetylene tetrabromide	3·0		
Methylene iodide	3·33		
Methylene iodide and iodine	3·6		
Mercury potassium iodide	3·2		Diluted with water.
Cadmium borotungstate	3·25		
Barium mercury iodide	3·5		
Mercurous nitrate (cryst.) *	4·3	70° C.	
Thallium silver nitrate *	4·5	75° C.	
Thallium mercury nitrate *	5·3	76° C.	

* These must be used at a temperature above their melting point. The specific gravity of the liquids should be determined each time they are used.

The solutions which can be diluted with benzene are usually the most convenient, on account of the ease with which the residues can be washed with benzene and dried. Mercury solutions have the disadvantage of being poisonous, cadmium borotungstate readily crystallises, and the solid salts need to be used at higher temperatures and so have many disadvantages.

which is sometimes employed for the rough portions of several minerals of various specific in forming a diffusion column by partially filling jar with a concentrated heavy liquid, and then filling ng part of the jar with a diluted solution. This is allowed out twelve to twenty-four hours until there is a gradual in specific gravity from that of the concentrated liquid ttom to that of the diluted liquid at the top. The test made by dropping in a small sample and noting the heights at ich the particles collect, fragments of known specific gravity ng dropped in as guides. By this means a rough idea of the minerals present may be ascertained.

The following solutions, according to Crook, are useful for this method of separation:

	Specific Gravity.
1. Bromoform diluted with benzene to	2·5-2·0
2. " alone	2·90
1. Methylene iodide diluted with benzene to	2·5-2·0
2. " " alone	3·30
1. Thoulet solution (Potassium mercuric iodide) diluted with water to	2·5-2·0
2. " " " alone	3·18
1. Klein solution (Cadmium borotungstate) diluted with water to	2·5-2·0
2. " " " alone	3·28

Magnetic Separation.—Some of the minerals found in sands possess magnetic properties, so that it is possible to separate them by the use of a magnet, or preferably an electro-magnet, with the poles ending in thin edges and capable of being moved so as to be spaced at varying distances apart.

A useful magnet described by T. Crook consists of two limbs, each 1 in. diameter and 4 in. long, wound with seven layers of 16-gauge wire, each layer having about forty turns. The two adjustable pole-pieces should be $1\frac{1}{4}$ in. wide and $\frac{1}{3}$ in. thick, slotted so as to be moved nearer to, or further from, each other, and secured by screws to the limbs. An 8-volt battery is quite sufficient for this instrument.

In use, the magnet is suspended over a smooth cardboard tray containing the sample to be examined. If desired, the most magnetic particles may be removed with a permanent magnet, and the "moderately magnetic" grains (p. 224) then removed by means of an electro-magnet with its poles about $\frac{1}{2}$ in. apart. Afterwards, the poles of the magnet may be placed only $\frac{1}{4}$ in. or rather less apart, and the "feebly magnetic" minerals (p. 224) may then be separated. The residue may be regarded as practically non-magnetic.

Electrostatic Separation.—The separation of minerals according to their electrical conductivity depends on the fact that minerals

having a high electrical conductivity are affected by an electric charge, whilst bad conductors remain inert. The apparatus recommended by T. Crook consists of two copper plates a few inches square, one of which has one surface coated with a layer of shellac, which is continued over the edge of the plate, forming a narrow strip on the opposite surface. The shellac-coated surface of one copper plate is placed next to the uncoated surface of the other, but is separated from it by two pieces of glass coated with shellac. The upper plate is charged electrically by means of an electrophorus, consisting of a plate of ebonite, resin, sealing-wax, or shellac, on a metal base and a circular metal disc of the same diameter with an insulated handle. If the plate of the electrophorus is rubbed with a flannel or piece of fur, a negative charge of electricity is induced in it, so that on placing the metal disc on its lower surface it is charged positively, and a complementary negative charge is given to the outer surface. This is removed by touching it with the finger. A small quantity of the sample of sand to be examined is placed on the upper side of the lower copper plate of the pair previously mentioned, and the disc to which the insulating handle is attached is placed upon the upper copper plate. The minerals which are good conductors of electricity will immediately adhere to the upper plate and can be removed therefrom, whilst the non-conductors remain on the lower plate. For accurate work, a larger apparatus operated by a more powerful current is preferable, but the simple device just described is often useful, especially if the test is applied to a sample from which the greater part of the quartz has been removed by panning (p. 256), or by means of a heavy liquid (p. 257).

Specific Gravity.—The specific gravity of sands, or the minerals therein, is determined either by the use of heavy liquids as described on p. 258, or by means of a specific gravity bottle. In the latter method, the most convenient form of specific gravity bottle consists of a small flask, with a neck graduated from 65 c.c. to 80 c.c., into which exactly 50 c.c. of water is introduced by means of a pipette. Then exactly 50 grams of the sand are placed in the bottle and the height of the column of water in the neck of the bottle is read. As the volume of liquid displaced by the sand is equal to the volume of the sand, the specific gravity is found by dividing the weight of the sand by the volume of liquid displaced. Thus, if 50 grams of a quartz sand cause the water in the bottle to rise to the 68·8 c.c., mark, that weight of sand must occupy a volume of $68{\cdot}8 - 50 = 18{\cdot}8$ c.c., so that its specific gravity is $50 \div 18{\cdot}8 = 2{\cdot}66$.

Apparent Density.—The apparent density of a mass of sand is determined by weighing a vessel of known capacity, filling it with the sand, and then re-weighing. The weight of the sand in grams divided by the capacity of the vessel in c.c. is the apparent density.

Volume-weight.—The volume-weight of a mass of sand is determined in the same manner as the apparent density, but a

ally employed. The weight of the sand in pounds pacity of the vessel in cubic feet gives the volume- ...ds *per cubic foot*. Alternatively, the weight of the grams divided by the capacity of the vessel in litres gives ...ume-weight in *grams per litre*. To convert "apparent ty" into "volume-weight," multiply it by 62·42 to obtain result in *pounds per cubic foot*. Conversely, to calculate the ...arent density from the volume-weight in pounds per cubic foot, multiply the latter by 0·016.

Refractoriness.—The refractoriness or resistance of a sand to heat (p. 229) is tested by mixing it with dextrin and water to form a paste, which may then be moulded into small tetrahedrons of the same shape as Seger cones (Fig. 21). These cones are dried and placed side by side with suitable Seger cones on a slab made of china clay and bauxite mixed into a stiff paste with water. The "cones" are pressed on to the surface of the slab so as to penetrate it slightly and so receive sufficient support to prevent them from falling. The slab with the cones is then placed in an electric, gas-blast, or Deville furnace until the test-piece bends over until its point just touches the base line of the support on which it stands. The number of the Seger cone which bends to the same extent under the same conditions as the test-piece indicates the refractoriness of the sand.

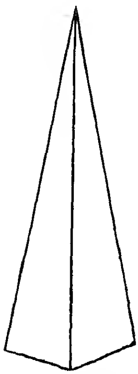


FIG. 21.—Seger cone.

If the cones have all bent before the test-piece, a fresh experiment must be made using a higher series of cones, whilst if none of the cones bend before the test-piece, a lower series must be employed. Sometimes, instead of regarding the limit of refractoriness as shown by bending, it is taken as the temperature at which the sharp edges of the cones become appreciably rounded as a result of fusion. It is therefore necessary in reporting a test, or in considering the reports of other tests, to know exactly which standard is taken before a satisfactory comparison can be made.

The heating must be slow and carefully controlled if an accurate result is to be secured, the most suitable rate of heating being a rise of about 10° C. per minute.

It is sometimes preferable to employ a pyrometer, so that accurate information as to the actual temperature at the indicating point may be obtained, though this is liable to error, because the pyrometer attains the temperature of the furnace much sooner than the interior of the test-piece, whereas the advantage of Seger cones lies in the fact that their temperature rises at approximately the same rate as that of the samples.

It is sometimes desirable to separate the sand into two portions by means of a No. 150 or No. 200 sieve, and to test the heat resistance of each of these portions separately. For instance, by such a

sifting the coarser and usually more refractory materials are removed and the finer and more fusible ones are isolated, so that their fusibility and its effects are more marked. In moulding sands, for example, where it is not the refractoriness of the sand as a whole that is required, but only its tendency to fuse in places, this separation of the more refractory constituents is of great value. The refractoriness test on either or both portions is carried out in the same manner as on the sample as a whole.

Melting Point.—When the true melting point of a sand or of one of its constituents is to be ascertained, only a few grains of the material can be used. Consequently it is necessary to view them through a microscope in order that their fusion may be clearly observed. For this purpose Doelter's electrically heated furnace may be used. It consists of a small electrically heated cylinder, which forms the furnace, the material being supported on the end of a stick of bauxite or graphite, or placed in a capsule (which must be considerably more refractory than the sample to be tested), with the hot junction of an electric pyrometer below it. The heat from the furnace is prevented from affecting the microscope objective by placing a disc of transparent quartz glass on top of the furnace. The remainder of the microscope may be shielded by asbestos sheeting. The sample is viewed through a microscope mounted above the furnace, the temperature at which it begins to lose shape being ascertained by means of the pyrometer. Unless the temperature is raised very slowly, it is necessary to have two observers—one to note the temperature recorded by the galvanometer, the other to look down the microscope and report when the fusion commences. It is necessary to make several tests so as to secure the requisite accuracy, as the chances of error when working on such a small scale are very large.

As the amount of material used in this test is necessarily small (or the completeness of the fusion could not be observed with sufficient promptitude), the results are usually lower than those obtained by the use of Seger cones. This difference between the fusibility and the refractoriness of a sand is due to the fact that the term "fusibility" is applied to the true melting point of individual particles, whereas the term "refractoriness" is applied to a mass of sand into which heat cannot penetrate so readily as it does into individual grains. If the heating in the refractoriness test could be sufficiently prolonged at the melting point of sand, the figures for refractoriness and melting point would coincide; this is, however, impracticable with a mass of sand, so that the figures differ as stated.

Porosity.—The total volume of the voids or pores in a mass of sand varies with the extent to which the sand has been compressed. Consequently, great care must be taken to reproduce the test under the same conditions as those under which the sand is used. For instance, the pore-space in a cubic foot of sand contained in a vessel 12 in. by 12 in. by 12 in. will not be the same

as in a vessel 432 in. by 2 in. by 2 in., because the sand in the lower half of the latter vessel will be under considerably greater pressure. For the same reason, there will be less pores in a mass of tamped, rammed, or compressed sand than in an equal weight of sand which lies " loose " in a shallow heap.

The volume of the pores in a loose sand may be determined by placing a measured volume (say 600 c.c.) of the sand in a graduated glass cylinder (Fig. 22) holding 1000 c.c., avoiding undue compacting by pressing or shaking. From another measuring-glass a suitable volume, say 300 c.c., of water is poured into the first glass and the level of the liquid measured. The percentage of voids in the sand is found by adding the volume of the water to the volume of the sand, and deducting the volume representing the final level of the water from this total. Thus, if 600 c.c. of sand and 300 c.c. of water are used, and the final level of the water is at the 800 c.c. mark, the volume of voids equals (600 + 300) - 800 = 100 c.c. Hence, 600 c.c. of sand contain 100 c.c. of voids; that is, the percentage of voids equals 16·7 per cent by volume. If the porosity of a compressed sand is to be determined, the same procedure is adopted, but the sand is first compressed to the desired extent in a vessel in which its volume can be accurately measured. Care should be taken—particularly in the case of a slightly compressed sand—not to separate the particles by pouring in the water too rapidly. To avoid this, it is sometimes preferable to admit the water through a tube entering near the bottom of the vessel containing the sand. This method of determining the porosity of a sand is not entirely accurate, as it is impossible to drive out all the air without disturbing the position of the sand grains; in some cases as much as 10 per cent of the pores may be left filled with air, and the reported porosity may be low to this extent. The theoretical porosity of a sand may be estimated from the apparent density (or volume-weight) and the specific gravity as

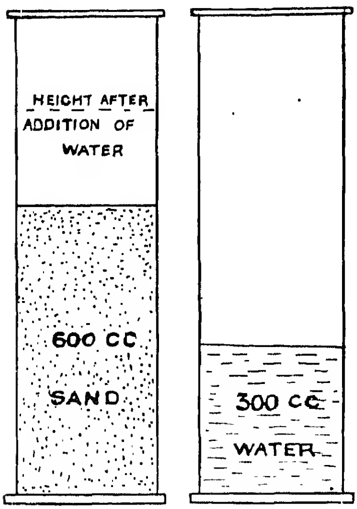


FIG. 22.—Porosity test.

$$P = \frac{100\,(S - A)}{S},$$

where P = the percentage by volume of the pores, S = true specific gravity, A = apparent density. Thus, a sand with specific gravity

2·54 and apparent density 1·187 will contain theoretically 53 per cent by volume of pores, but the pores which can be filled with water would be somewhat less than this proportion. Moisture in a damp sand will reduce its porosity, and should therefore be determined. The porosity may then be calculated from the following formula, suggested by Taylor and Thompson, in which W = the weight of exactly 1 cu. ft. of the moist sand, P = the percentage of moisture in the sand, and S = the true specific gravity of the sand.

$$\text{Per cent of absolute voids} = \left(1 - \frac{W - \frac{WP}{100}}{62{\cdot}3\ S}\right)100.$$

The air voids may be found by deducting from the percentage of absolute voids, the percentage volume of moisture ; the latter is found from the formula

$$\frac{\text{Per cent moisture by weight} \times \text{weight of 1 cu. ft. of material}}{62{\cdot}3}.$$

Table LVIII., due to Taylor and Thompson, shows the percentage of voids for sand of different weights per cubic foot and different moisture contents.

Permeability is a term used to indicate the extent to which gases or fluids will pass through a bed or layer of sand of certain thickness. It is specially important in connection with moulding sands and sands used for filter-beds.

A very satisfactory method of testing the permeability of a sand, used by the author, is carried out on the following principle :

A circular metallic box (Fig. 23, p. 265), 3 in. diam. and $1\frac{1}{4}$ in. deep, with a flanged rim at the top, has the bottom cut out and replaced by a piece of wire gauze of any suitable mesh. On this gauze is laid a sheet of thin blotting-paper, and the case is filled with the sand to be tested, to a height of exactly 1 in., care being taken that it is as nearly as possible in the same state of compression as it is when in use ; thus, moulding sands will need to be tamped so as to secure the necessary compactness. In testing sands of this kind, the author, in order to preserve the conditions of normal ramming, usually places the empty case in a larger mould in course of formation, and removes it when filled, the space left in the larger mould being afterwards repaired. A second sheet of blotting-paper is laid on the sand and a flanged pipe is then clamped firmly on to the case, care being taken to avoid breaking the structure of the sand. Water is poured gently into the flanged tube to a height of exactly 40 in. (or exactly 1 metre) and the appliance is suspended above a glass measure. The time taken for 100 c.c. of water to flow through the sand into the receiver is a measure of the permeability. In more exact experiments the level of the water in the flanged tube must be kept constant. If care is taken in

TABLE LVIII.—POROSITY OF MOIST SAND

Weight of 1 cu. ft. of Sand.*	Percentages of Absolute Voids in Material containing Moistures by Weight.†					Moisture by Volume corresponding to 1 per cent by Weight.
	0 per cent.	2 per cent.	4 per cent.	6 per cent.	8 per cent.	
70	57·6	58·4	59·3	60·1	61·0	1·1
75	54·5	55·4	56·4	57·3	58·2	1·2
80	51·5	52·5	53·4	54·4	55·4	1·3
81	50·9	51·9	52·9	53·9	54·8	1·3
82	50·3	51·3	52·3	53·3	54·3	1·3
83	49·7	50·7	51·7	52·7	53·7	1·3
84	49·1	50·1	51·1	52·2	53·2	1·4
85	48·5	49·5	50·6	51·6	52·6	1·4
86	47·9	48·9	50·0	51·0	52·0	1·4
87	47·3	48·3	49·4	50·4	51·5	1·4
88	46·7	47·7	48·8	49·9	50·9	1·4
89	46·1	47·1	48·2	49·3	50·4	1·4
90	45·5	46·5	47·6	48·7	49·8	1·4
91	44·8	45·9	47·0	48·2	49·2	1·5
92	44·2	45·4	46·5	47·6	48·7	1·5
93	43·6	44·8	45·9	47·0	48·1	1·5
94	43·0	44·2	45·3	46·5	47·6	1·5
95	42·4	43·6	44·7	45·9	47·0	1·5
96	41·8	43·0	44·1	45·3	46·4	1·5
97	41·2	42·4	43·6	44·7	45·9	1·6
98	40·6	41·8	43·0	44·2	45·3	1·6
99	40·0	41·2	42·4	43·6	44·8	1·6
100	39·4	40·6	41·8	43·0	44·2	1·6
101	38·8	40·0	41·2	42·5	43·7	1·6
102	38·2	39·4	40·7	41·9	43·1	1·6
103	37·6	38·8	40·1	41·3	42·5	1·6
104	37·0	38·2	39·5	40·8	42·0	1·7
105	36·4	37·6	38·9	40·2	41·4	1·7
106	35·8	37·0	38·3	39·6	40·9	1·7
107	35·2	36·4	37·7	39·0	40·3	1·7
108	34·6	35·9	37·2	38·5	39·7	1·7
109	33·9	35·3	36·6	37·9	39·2	1·7
110	33·3	34·7	36·0	37·3	38·7	1·8
115	30·3	31·7	33·1	34·5	35·9	1·8
120	27·3	28·7	30·2	31·6	33·1	1·9
125	24·2	25·8	27·3	28·8	30·3	2·0
130	21·2	22·8	24·4	25·9	27·5	2·1
135	18·2	19·8	21·4	23·1	24·7	2·2
140	15·2	16·8	18·5	20·2	21·9	2·2

* The table is based on sand having a specific gravity of 2·6.

† The percentages of absolute voids given in the above columns include the space occupied by both the air and the moisture. To determine the percentage of air space, multiply the figure in the last column, opposite the weight of sand under consideration, by the percentage of moisture by weight, and deduct the result from the percentage of absolute voids already found.

making the test, a series of results from the same sand are very concordant.

In testing moulding sands by this method it will be found that whilst the results made by the same moulder are very constant,

those with cases filled by different moulders differ so greatly tha. no comparison is possible. Hence, in testing fresh deliveries of sand, it is important that all the test-pieces should be made by the moulder who is going to use the material. At the present stage this test is of value in works for the manager's own use, but not for comparison with the results obtained by others, the differences obtained by unconscious variations in manipulation being so great. In a modification of this test the author endeavoured to substitute air in place of water, but the variations in the amount of air penetrating through the same block at different times, as well as with different tests of the same sand, made the use of air appear impracticable. C. P. Karr claims to have obtained concordant results with air by means of a similar apparatus, but he tamps the sand by means of three blows delivered by a weight of 14 lb. falling from a height of 2 in.

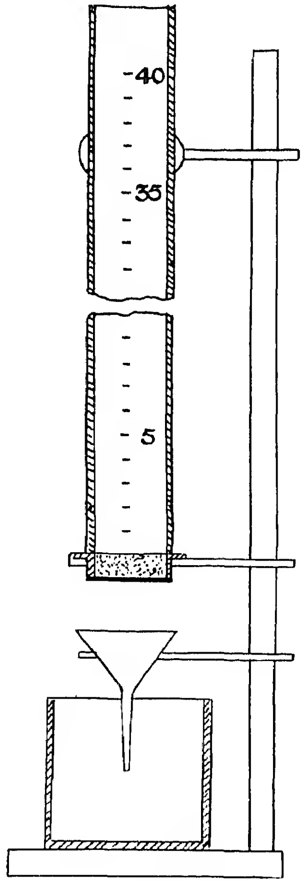


FIG. 23.—Permeability test.

Sharpness.—The sharpness of sand cannot be expressed numerically, but a careful microscopical examination will usually enable the relative angularity of the grains of two samples to be compared in a few minutes.

Strength.—The measurement of the tensile, compressive, and transverse strengths is useful in some cases, but usually the value is very low and the errors of experiment are so great as to destroy the value of the results.

The greatest difficulty is experienced with sands which are practically free from clay, as these have no binding power, and therefore a mass of such sand has little or no strength, though that of the individual grains may be enormous. Consequently, tests of the strength of sand are usually limited to (*a*) impure sands containing a considerable proportion of clay—such as moulding sands, and (*b*) mixtures of sand with Portland cement or lime, such as are used in concrete and mortars. Although the latter does not show the strength of the sand alone, it is often useful for comparative purposes.

The *compressive strength* or resistance to crushing may be determined by ascertaining the maximum weight which can be

carried by a cube of sand with 2-in. sides, the weight being applied in the form of a light aluminium cylinder with a base larger than that of the cube of sand. Water or mercury is run into the cylinder until the cube of sand loses its shape; the weight of the cylinder with its contents then represents the pressure applied to the cube of sand. So far, the results, though interesting, are far from constant with different batches of the same sand, though consecutive cubes made from a small sample yield concordant results. The compressive strength of mixtures of sand with cement or lime should be made in a hydraulic press designed for the purpose, as the pressure required is greater than can be applied accurately by means of a simple weight. It is usually better to have such tests made by an expert.

The *transverse strength* of a sand is determined by making bars of the sand each 1 in. square in section and 4½ in. long. These bars are placed on knife-edge supports, 4 in. apart and loaded in the centre by means of a knife-edge to which is attached a small pan of aluminium, into which shot or mercury may be poured. The breaking stress is reported as pounds, or fractions of a pound, per square inch cross-sectional area of the test-piece. This test is very delicate on account of the low stress required.

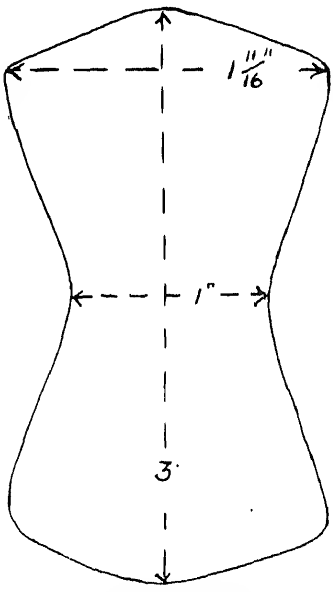


Fig. 24.—Tensile test-piece.

Another simple method of testing the transverse strength of a sand is to make a number of test-pieces 1 in. square in cross-section and about 12 in. long. They should be placed on a glass plate and gradually pushed over the edge; the amount which overhangs before breaking is a rough measure of the transverse strength of the sand.

The *tensile strength* of a sand is determined by placing a test-piece of the shape shown in Fig. 24, which is made in a mould of suitable shape. The mould is slightly oiled and placed on an oiled plate of glass or metal, and more than sufficient sand or mixture[1] to fill the mould is put in by means of a trowel and tamped carefully until the mould is filled evenly, and the water rises to the

[1] It is seldom possible to determine the tensile strength of a clean dry sand, except by mixing it with a definite proportion of Portland cement and water and comparing the tensile strength of the product with that of similar mixtures composed of other sands.

surface, giving it a shiny appearanee. The superfluous paste is then removed by drawing the edge of the trowel across the top of the mould. Care should be taken that the mould is not vibrated during the test, or the strength of the test-pieees will be reduced.

Moldenke employs a separable frame of hardwood 1½ in. thick. This frame may have one or more spaces, so as to produce any convenient number of test-pieces at a time. Each space is loosely filled and heaped with the sand to be tested. The sand is then compressed with a hand-rammer to ¼ in. over the top of the frame, and this surplus is struek off flush. Strips of wood the size of the test-pieces and exactly ½ in. thiek are laid on the sand over the spaces and are pressed flush with the frame so as to compress the already slightly packed sand and make the test-pieces exactly 1 in. thick. The frame is then taken apart and the test-pieces are ready for use. For mixtures of sand with cement or lime a brass mould is to be preferred.

In testing the strength of sands, the proportion of water used in mixing must be taken into consideration. The effect of different proportions of water is shown in Table LIX. by Moldenke.

Table LIX.—Effect of Water on the Strength of Sands

Kind of Sand.	No. of Samples.	5 per cent Water.	7½ per cent Water.	10 per cent Water.	Dry Sand.
Fine . .	18	0·13	0·16	0·15	1·28
Medium . .	10	0·76	0·22	0·11	1·68
Coarse . .	48	0·42	0·31	0·24	1·88

The figure given is the strength of the sand in pounds per square inch.

A large proportion of water in coarse sands is relatively more detrimental than with finer sands, as the coarser ones have a smaller surface area.

If Portland cement is used as a binder the test-piece should be kept under water at a uniform temperature until ready for testing. If this is not desired, the test-pieces should be kept in a damp atmosphere for at least twenty-four hours before testing.

The test-piece is placed between the jaws of a tensile machine, such as that shown in Fig. 25, and tension is applied by means of shot which is poured into a metal can until the test-piece is broken. The load at the time of breaking is noted and the strength of the sample reported as pounds per sq. in., or in other convenient terms. The various strengths of sands are usually compared with those obtained by using "Standard Leighton Buzzard Sand."

Viscosity.—The rate of flow of a sand may be determined by passing a known quantity of it through an orifice of definite size and noting the time taken. Various sands may be compared in

this way, the time taken being a measure of the viscosity or rate of flow. It is essential that the same vessel should be used throughout the whole series of tests, as several factors, such as the shape of the cylinder, the nature of its interior surface, etc., can seriously affect the result (see p. 225).

In spite of the difficulties experienced in testing sands and in formulating satisfactory conclusions from the results of such tests, their value is unquestionable, and as users accustom themselves more and more to the study of the properties of the sands they

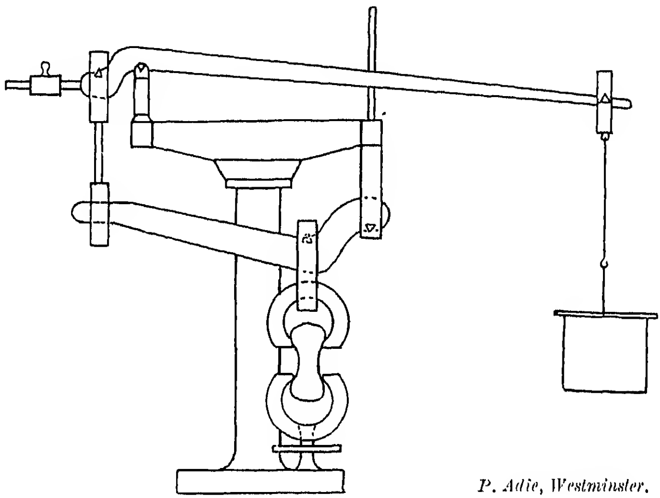


FIG. 25.—Tensile testing machine.

use, the greater will be the progress made. There is an increasing tendency to detailed standardisation of the different sands employed abroad, especially in connection with moulding sands, on account of the common use of artificial mixtures, but in this country there is such an abundance of natural sands which are sufficiently suitable, both as regards composition and physical properties, that there is less inducement to improve these natural materials. Nevertheless, a careful study of the sands used for different purposes is very necessary for efficient work. The chief difficulty is that the most effective tests are beyond the capability of the ordinary user, but this does not make their use unnecessary; on the contrary, they should be carried out by a suitable expert.

CHAPTER VII

PROSPECTING, MINING, AND QUARRYING SAND AND SAND-ROCKS

In searching for sands it is of great importance that the prospector should have a good geological knowledge, so that he may know where to expect sands suitable for his purpose, and what kind of sands are likely to occur in any particular formation. The most important general information of the geology of sands has been given in Chapter II.

A rough idea of the situation of the sand deposits in the United Kingdom may be gained by a study of geological maps, such as those published by the Geological Survey; more detailed information, however, can only be obtained by a careful study of the site itself, taking advantage of the clues provided by the hills, valleys, cuttings, old quarry faces, etc.

In order to ascertain whether any sand deposit is likely to be of commercial importance, it is necessary to obtain the following information:

The extent of the beds must be found by a careful study of the surrounding land. Any exposures of the beds, such as in old quarry faces, etc., should be examined to see whether the particular bed under consideration is present, and, if so, its thickness and whether it is readily accessible.

The slope of the beds in different localities will give some idea as to their extent. Thus, if the beds are horizontal, they may extend for a considerable distance, whilst if they slope at a steep angle they may only be accessible over a very short area on account of the thickness of the overburden. In some cases it may be found that a bed becomes thicker in one direction and thins out until it disappears in another direction, or it may change in quality, being valuable in one part of the bed but quite useless in another.

Faults, fractures, slips, hitches, etc., caused by volcanic or other action may have occurred in the district and may have broken up a bed, thereby causing trouble in prospecting for and in obtaining the material. Such occurrences must be carefully studied, their direction being recorded on a map drawn to a sufficiently large scale.

In some cases it may be found that a huge mass of rock may be intruded into a deposit, and careful study is then necessary in order to determine where the most accessible parts of the sand deposit lie.

If the deposit is near the surface of the ground, it is necessary to know what quantity of overburden or "callow" lies above the bed in different localities. Thus, in some parts it may be only a few inches, whilst in another part of the property it may be many feet in thickness, rendering the winning of the sand much more difficult and costly.

It is therefore necessary in prospecting a bed of clay to map out carefully the whole area in both horizontal and vertical directions, indicating upon the maps the depth of the deposit below the ground in different localities, the inclination of the deposits, their thickness, and other important information. By this means the value of a deposit may be ascertained with some degree of accuracy, and arrangements can be made for it to be worked in the most economical and remunerative manner.

It is desirable to divide the area to be examined into a considerable number of equal parts and to make a pit or boring (*infra*) in the centre of each. The number of pits or borings may be minimised by a careful examination of the deposit by other means, as such borings are very expensive and some parts may be left untested in order to economise expenditure, but it is important not to take too great risks in this direction, otherwise a deposit may be found to run out after only a very short period of working. The results of any pits or borings made should be noted upon the maps of the deposit, and the spaces between the borings filled in as accurately as circumstances permit.

Boring.—For testing deposits which lie at a considerable depth below the surface the use of some type of boring apparatus is necessary. As these are costly, require some skill in use, and are only wanted temporarily, it is better to employ a firm of professional borers who will do the work for a definite price.

The apparatus used for making such borings consists of a *core drill*, which is a long tube, the lower end of which is fitted with a cutting edge or, preferably, with diamonds, so arranged as to produce a core which can be removed either in the drill or separately. They are usually started by hand and are then continued by machinery.

The examination of the material obtained by boring is by no means easy, as in the first place the passage of the tool may cause some admixture of different strata and so produce an incorrect sample. It is therefore necessary to take the utmost precautions to obtain a representative sample. Too much care cannot be taken to ensure accuracy in this respect.

If the total length of the cores withdrawn does not agree closely with the depth to which the boring tool is sunk, seriously erroneous conclusions may be drawn. When a bed of apparently suitable

material has been found, samples should be taken from different parts of the bed in the manner described on p. 234, and carefully tested so as to determine their value for special purposes.

Various rough tests may be applied on the spot in order that a general idea of the quality of the deposit may be obtained. The appearance of a sand (p. 205) may help somewhat in estimating its quality, though it is not altogether reliable. The application of a little hydrochloric acid to a small sample will render the presence of any calcium carbonate obvious. The compactness or friability, which to some extent determines the ease of working, may be tested by digging with a spade, or breaking the stone, if it is a rock, with a hammer. Other more detailed tests, such as those described on pp. 235-268, must also be carried out, the number and extent depending on the use to which the sand is likely to be put.

Before finally deciding to work a deposit of sand or sandstone, it should always be tested sufficiently exhaustively, so as to be perfectly sure that the quality is satisfactory for the purpose in mind, and the tests should be carried out on a sufficiently large scale to render it reasonably certain that the material will be satisfactory on a commercial scale.

Preliminary tests on a small scale, if properly carried out, are the best means of saving costs in prospecting, and should always precede larger tests, but the latter should never be omitted if the former give favourable indications as to the value of the material. Neglect of this precaution leads to the waste of enormous sums of money by prospectors and capitalists.

As the success or failure of the enterprise may eventually depend upon the accuracy with which the prospection and tests have been made, and the reliability of the indications given, it is wise to place the whole of the investigation in the hands of an expert. This is the more necessary as, even when the nature, situation, and extent of the deposits are known, there are several highly important matters—such as the planning of the mine or quarry, precautions against flooding, and the disposal of the overburden—to be considered.

The location of the site relative to the market for the product is a further factor requiring consideration, as it has not infrequently happened that a firm has suffered many inconveniences due to unsuitable location, when a little more knowledge of the distribution and sale of the material would have saved them much trouble.

The **valuation** of a deposit of sand or sandstone must be based upon (1) its size, (2) its location, (3) the cost of bringing the material to the place where it will be used (*i.e.* to the surface, or on to the railway or boat, and thence to the user), and (4) the rate at which it will be obtained. The last factor is especially important to the purchaser, as the present value of a sand deposit, portions of which cannot be used for some years, is necessarily different from what it would be if the whole deposit were to be used up in a single year. Thus, if the present value in pounds equals C, the

rate of interest for similar investments (usually taken as 4 per cent) $= r$, the number of years required to work out the deposit $= k$, the value of the sand or stone to be removed annually or the royalty paid per annum $=$ V pounds sterling, then

$$k = 1 + \frac{r}{100},$$

$$C = \frac{100\ V(k^n - 1)}{rk^n}.$$

For practical purposes this may be simplified into Table LX., in which the first column shows the duration of the sand or stone deposit, and the second and third the number of times the yearly royalty or the value of the sand removed annually (V), which is equivalent to the total present value of the deposit.

TABLE LX.—VALUATION OF SAND BED

Duration in Years.	Present Value.	
	Interest at 4 per cent.	Interest at 5 per cent.
10	8·11 V	7·72 V
15	11·11 V	10·39 V
20	13·58 V	12·46 V
25	15·62 V	14·10 V
50	21·48 V	18·13 V
100	24·50 V	19·85 V
200	25·00 V	20·00 V

If R $=$ the royalty in pence per ton, and T $=$ the average number of tons to be removed annually,

$$V = \frac{RT}{240}.$$

It will be noticed that the rise in value after fifty years is very small, and may usually be neglected. Indeed, few persons would give more than sixteen times the value of the sand removed annually. Even for the most valuable sand deposit and for most sands in this country the value of the ungotten material is not measured by its volume, but is very little larger than the agricultural value of the land. Thus a field containing an unworked bed of sand in a district where the agricultural value of the field is £30 per acre will not usually have its value increased by more than £20 per acre as a result of useful sand being present. In some localities where special conditions prevail a higher value will be placed upon the land.

Selecting a Site.—When a deposit of sand or sandstone has been thoroughly examined and found suitable, it is necessary to decide upon the method in which it is to be worked and the manner in which the deposit is to be opened out.

It is of great importance, before actually opening out a quarry or sand-pit, that the site should be carefully and skilfully chosen, as a mistake in this preliminary work may eventually result in the failure of a venture which ought to have been highly successful.

A considerable number of quarries have been started on the wrong side of a hill, so that no advantage can be taken of the dip or lie of the strata. In other cases, the men work "straight ahead" into a hillside when it would be much cheaper to "edge" the hill and to work at right angles to the present direction; this is especially the case where there is a thick covering of overburden or useless material. Sometimes a site is chosen which is suitable in some respects, but is, on the whole, inferior to another possessing a single drawback which could be overcome by a little ingenuity. Again, a site is sometimes selected near the top of a high hill and a long way from the railway or road, yet sand of the same quality is available much nearer to these facilities. In these and many other ways, the selection of a suitable site is of paramount importance.

In selecting a site, special attention should be paid to (i.) the overburden, (ii.) the position of the dip and strike of the strata, (iii.) the drainage possible, (iv.) the water-supply, (v.) the haulage grade to crushers and from thence to the railway, (vi.) the position of the railway and the cost of a siding, (vii.) suitable sites for power-station, crushers, etc., and (viii.) the transportation facilities. All these items are of great importance, and if any one is wholly unsatisfactory, the site should usually be abandoned.

The thickness of the overburden and the cost of removing and disposing of it very largely govern the value of a given sand deposit, for it is obvious that an excessive thickness of useless material cannot be profitably removed to clear a comparatively thin bed of sand. Hence, the site should be chosen so that there is a minimum thickness of overburden to be removed. Whether this can be done economically depends on the thickness of the underlying sand and on local conditions respecting the disposal of the overburden.

The steepness or dip of the strata has a serious effect on the cost of haulage, especially if it is away from the face of the quarry, so that all the sand has to be hauled up an incline. Such downward-dipping strata also cause further trouble by acting as catch-pits for rain-water, unless a suitable system of drainage is installed.

The **Lay-out and Planning** of the quarry or sand-pit cannot receive too much skilled attention, for much of the difference between success and failure in working sand depends on the efficiency of the system used. Each quarry or pit presents its own special problems, and unless the working is carefully and skilfully planned, and the local considerations duly taken into account, there is likely to be failure.

In the first place, the stability of the quarry or pit must be assured, and all necessary precautions to secure it must be taken;

otherwise, there may at some time be a serious landslip, and lives may be lost. The precise precautions to be taken to ensure stability depend on the locality, but as a rule the width of the bench or platform should be equal to the length between each bench and at least half the height.

The quarry should be made in the side of a hill rather than by excavating below the ground level, though in some cases the latter is unavoidable. The quarry face should not be worked to a height of more than 25 ft. at a time; that is to say that if a greater height of face is desired, it should be worked as two or more separate benches or sub-faces, each of which is not more than 20-25 ft. in height. Excessively high faces are not economical, as they involve special precautions to ensure safety as well as the use of excessively large cranes, etc., which increase the cost of working. These objections are avoided by working in sections or benches of 20-25 ft. in height. High faces cannot usually occur in a sand-pit, but they are sometimes found in sandstone quarries.

The site having been selected as skilfully as possible, the man in charge of the lay-out or working plan should exercise his skill and ingenuity in arranging that all the operations in the quarry or pit shall be planned so as to avoid all methods that place an unnecessary burden on labour. Thus, excessive rehandling of material, complexity in transportation systems, and loss of time through conflict of various operations should be avoided. In many cases this can be accomplished by a modification of the method, involving no heavy expenses in the purchase of new equipment. In large quarries, especially in the United States, hand methods are being largely superseded by mechanical means, not so much as a result of a pronounced shortage of labour as because the mechanical methods are cheaper, quicker, and promote rapid increase in production. When labour is cheap and plentiful, the advantages of mechanical equipment, particularly in small quarries, are questioned by many quarry-owners, but in large quarries the advantages of mechanical equipment are generally recognised. The adoption of such equipment has, however, been slow in many places. This is due to various causes, the chief of which are conservatism, lack of information on modern equipment, and lack of capital. In some sand-pits and sandstone quarries in the British Isles the use of rapid-working excavating machinery would be quite unjustifiable, because the total quantity of sand or stone to be moved in a year is so much less than the output of the smallest size of machines. For instance, a steam navvy will seldom pay if there is less than ten years' continuous work at three-quarters of its full capacity, or say a quarter of a million tons in all. For smaller outputs to be worth the installation of a machine, either labour must be scarce or there must be some other consideration, such as the necessity for completing the work as rapidly as possible, the cost of which can be recovered in the price obtained for the sand.

A fruitful source of waste in many pits is the needless handling of material, owing to the sand being unloaded and reloaded unnecessarily, or to its being dumped in places that require excessive labour for its subsequent removal. Such excessive rehandling may be due to lack of equipment, to faulty design, or to carelessness and oversight, but whatever the cause, its effects on the profits are obvious. Such unnecessary handling is always costly, and in times of shortage of labour it is imperative that radical changes should be made to remedy such faults.

In laying out a sand-pit, and especially a quarry, it is necessary to look well ahead and to consider what will be the effect of the present arrangements when the quarry has been working fifteen to twenty years. A further matter of importance is the "weight × distance" factor of all materials moved, which must be kept at a minimum. Many men in planning quarries pay much attention

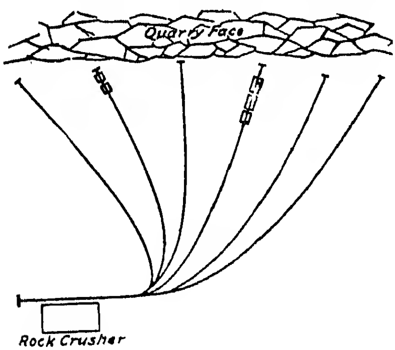


FIG. 26.—Lay-out of lines in quarry.

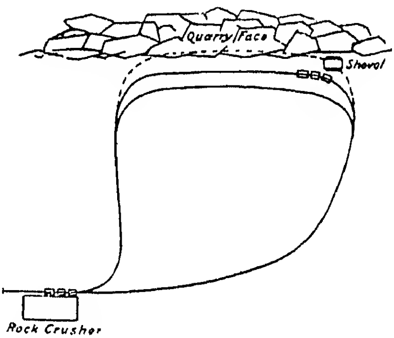


FIG. 27.—Lay-out of lines in quarry.

to the weight of the material to be moved, but they overlook the distance to which it has to be taken. In view of this fact, the disposition of the tram-lines or tracks leading from the quarry face to the works is a matter of great importance. If these are wrongly placed, either the men will be hampered in their work or great expense may be incurred in putting the tracks in a suitable position, or the cost of transport may be excessive. The ordinary method is to arrange a series of tracks radiating from the main line, or pair of main lines, to various parts of the quarry face (as in Fig. 26). In many respects this is a good arrangement, but it has the minor drawback of compelling the men taking trucks or wagons to the face either to wait until the track is clear or to throw the empty wagon off the line and reinstate it later ; the latter process involves unnecessary labour, delay, and damage to the wagons. By using double tracks, this trouble may be largely avoided, though even then it is sometimes difficult to secure a wholly satisfactory method of delivering empty wagons and removing full ones.

When conditions permit, it is often better to arrange a track

along the quarry face and to have the material thrown into the wagons on this track. Some quarrymen object to this, because the tracks have so often to be altered, but in many cases this is less serious than is often supposed. When a steam navvy, grab, crane, or other mechanical loader is used, the arrangement of a track along the quarry face (Fig. 27) is by far the simplest and best.

No one method is equally satisfactory in all cases, and the quarryman who would get the best results must exercise considerable ingenuity and skill.

The **Position of the Machinery** relative to the quarry face and to the spoil bank on which the overburden is tipped requires careful consideration. The machinery ought obviously to be placed in a position where it is free from all danger from landslips or explosions. It should also be placed in such a position as to be out of the way of developments of the quarry face, spoil bank, or railway siding, and yet convenient for the supply of power and readily accessible from the works. Here again no general rule can be applied to all cases, but it is usually wise to keep the machinery well in front of the quarry face and somewhat below the quarry floor so as to make full use of gravity. The distance between the quarry face and the machinery ought to be sufficiently large to accommodate the spoil bank, unless there is some hollow somewhere which can be filled with overburden and can never be required for any other purpose. A serious mistake which is often made in planning a sand-pit or quarry, is to place either the spoil bank or the machinery on good material, which cannot, therefore, be quarried, and is to all intents and purposes lost.

It is an excellent plan to allow space for machinery capable of producing five times the anticipated maximum output of the quarry, as this allows of ample development, keeps the plant well out of harm's way, and generally facilitates the working of the quarry.

The chief **Sources of Power** in quarrying or mining sand, sandstones, etc., are steam, producer gas, and electricity, with compressed air or water (wave transmission) as secondary sources of power. The use of these in connection with drilling is described on p. 300; the power required for crushing, transport, etc., is more conveniently described under these respective subjects, and it must here suffice to state that in planning a quarry or mine, ample power should be provided, even though it is not all required at first; as the works increase in output, it is then easy to proceed, whereas in the absence of provision for ample power the whole future of the property may be jeopardised.

The other chief items requiring attention in planning any given site or quarry are: (i.) the floor; (ii.) the drainage; (iii.) the removal of the overburden or stripping; (iv.) the methods of extracting the sand or stone; (v.) the removal of the material to the crushers; and (vi.) the position of the various accessories.

The **floor** of the pit or quarry, where possible, should slope

away from the face, and its lowest point should, where possible, lie above the drainage-level of the surrounding area, so as to avoid the necessity of pumping. Where the nature of the strata permits it, an almost level floor is in every way preferable to a steeply sloping one. The arrangement of the floor so as to ensure good drainage is very important, and failure in this respect is one of the commonest causes of loss. If the beds are developed down the dip of the strata, accumulations of water may occur at the working face after very heavy rain, and cause a temporary suspension of operations, with consequent loss of labour. If the beds are worked in the opposite direction, the water will drain away, and no accumulation of water at the face will be possible. Where the sand or stone lies in horizontal beds, the working is rendered very simple, as the smooth floor requires little or no grading or ballast for tracks, and track-laying may be accomplished with a minimum of labour. A smooth floor also facilitates loading.

The **drainage** of a pit or quarry is a matter which should have more attention than is commonly paid to it. The wise manager will always endeavour to secure natural drainage as far as possible, and even where some pumping is necessary it is most economical to attempt to secure natural drainage for the site as a whole, and to pump the water from a sump or well, into which the water from the rest of the workings drains naturally. This can usually be secured with a little forethought and planning, so that there is a slight slope in the floor of the quarry towards one or more definite sumps or wells. Unless this is done there will be a series of delays, much slow working and some accidents, because the face and floor are too wet. The above precautions may seem to be an unnecessary expense, but the results are well worth the cost. In some old quarries with which the author is acquainted, it has even been found profitable to abandon the existing face and to reopen the quarry at a different point, so as to ensure efficient drainage; the lower costs of working the quarry under dry conditions rapidly paid for the cost of reopening the stone at a different point. Where such a course would be regarded as too drastic, it is usually possible to work along the strike, *i.e.* at right angles to the dip of the strata, in order to secure natural drainage of the sections or benches.

GETTING THE MATERIAL

The methods of working deposits for sand vary very greatly according to the nature of the deposit. Sand-bearing deposits may be roughly divided into the following groups:

1. Loose or slightly coherent sands.
2. Harder rocks, such as quartzites, sandstones, ganister, etc.

The deposits may or may not be covered by a certain amount of overburden, so that the processes of working will be described under the following heads:

1. Removal of overburden.
2. Working loose sand deposits in open quarries or pits.
3. Working sand rocks in open quarries.
4. Working sand rocks in mines.

Removal of Overburden

In some localities where the overburden is thick, its removal involves problems in quarrying which are almost as great as those in connection with the removal of the sand itself. In most cases, however, it is not profitable to remove more than 6 ft. of overburden in order to obtain direct access to the sand beneath.

The overburden to be "stripped" or "ridded" is usually of a relatively soft nature, and can be removed either by digging by hand or by excavating machines, or, if sufficiently thick or accessible, by means of a steam navvy. If the quarry is near a watercourse, the ridding may sometimes be effected by washing away the material hydraulically with powerful jets of water applied by fire engines or similar appliances. In such cases powerful hoses are used, through which a stream of water 1½-2 in. diameter at a pressure of 40-60 lb. per sq. in. is directed on to the material to be stripped, and the latter is rapidly washed away. If water is rather scarce, the product from the washings may be collected in settling ponds and the clear water used over again, but this method of stripping gives the best results when the waste material can be discharged into a river, or deep lake, or even into the sea. This is a cheap method, but it can only be used where there is an abundant supply of water and a large dumping area at a suitable level.

The nature and amount of material to be moved governs to a great extent the methods to be used. The most expensive method of removing overburden is by pick, shovel, and wheelbarrow or wagon. These tools can only be applied economically where the overburden is very thin or the conditions are such that other implements cannot be employed. Under average conditions, a man may be expected to shovel into an ordinary wagon 20 cu. yds. of light sandy soil or 15 cu. yds. of heavy soil, well loosened, per day. In shovelling ordinary earth, a large number of experiments have shown that the most economical load for an average shovel is 21 lb. The size of the load and the shape of the spade or shovel vary with the material being handled, and if these matters are properly cared for there is a possibility of increasing many a man's output by about 50 per cent, as most men lift about 15 lb. on each shovelful. This increase in output comes partly from experience and industry, but chiefly by using a shovel of a shape suited to the work and seeing that the man is taught how to use it.

In loading wagons, a man working under normal conditions, and using a D-handled shovel, will throw the following amounts in ten minutes:

Height of Wagon.	Volume of Earth thrown.
3 ft.	1·4 cu. yds.
4 ft.	1·33 ,,
4 ft. 6 in.	1·2 ,,
5 ft.	1·1 ,,
5 ft. 6 in.	0·9 ,,
6 ft.	0·8 ,,

In casting ordinary earth through a horizontal distance not exceeding 10 ft. a man will average 18 shovelfuls per minute.

In loading wheelbarrows or low carts without an end and not exceeding a height of 33 in., a man casting average earth will have an output of about 15 shovelfuls per minute.

The influence of several men on each other is important, and a good foreman with a gang of contented men will get through more work, and at each throw will deliver a larger shovelful, than if the men are discontented or isolated. As the number of shovellers to each wagon is increased above four the average efficiency will decrease, and if ten shovellers were employed on one truck the average efficiency would not exceed 85 per cent.

A correct position is essential in shovelling, and it is well worth while to teach a man how to dig and shovel properly. Few labourers know how to move their bodies, or to handle the shovels so as to make the work easy for themselves and rapid for their employers. The men should be placed at their work according as they are right-hand or left-hand workers. The right-hand man casts his load from his right side, while the left-hand man throws from his left. Where possible, the men should be trained to shovel either right-handed or left-handed. Standing close up to the material, the man should bend his back and his shoulders forward, not as in picking an article from the ground, but so that he is well balanced on his feet, one leg being well in front of the other. In digging, the spade should be pressed directly, then lowered back and lifted horizontally with the load. In shovelling, on the contrary, the wrist of one arm should be laid on the knee of the front leg, and the other knee should rest against the end of the shovel. The shovel is thrust into the mass by the movement of the body, the object being to throw the weight of the body into the motion used in thrusting the shovel. When the shovel is full, the knees and back are straightened, without altering the position of the hands. The load is then cast away by turning the body when the height and distance are not great. With longer throws, the arms must be used to give the shovel the necessary motion.

Scrapers.—Apart from picks and shovels, and when only a small outlay of capital is available, a plough and scraper are among the most efficient implements which can be employed, on account of their adaptability and comparatively cheap working cost. The plough is necessary to loosen the earth before the scraper can be filled. A horse-drawn drag scraper is more suitable for close work and short hauls, and a wheel scraper for open work and long hauls.

The latter has a larger capacity than the former, and, being on wheels, is much easier for the horses. One plough moving fairly steadily can loosen about 300-400 cu. yds. per day. Better results can usually be secured in very hard or tough ground by a scarifier drawn by a tractor or roller, but in ground of this nature blasting is usually more economical when the depth of the material to be loosened exceeds 3-4 ft.

Horse-drawn scrapers have a gross capacity of 3, 5, and 7 cu. ft. and a net effective capacity of about 60 per cent of these quantities. Each scraper will place under average conditions 50-65 cu. yds. of compacted fill per day, but a scraper hauled by a drag-line has four times this output. Ploughs and similar appliances are only suitable where the overburden consists of a relatively soft material such as " soil," clay, or gravel.

Drag-line excavators, which consist of a rectangular tray, or skip, with a cutting or scarifying device at the front, are sometimes used for removing overburden. The tray is suspended from an elevated ropeway in such a manner that it can be drawn along the ground by a hauling rope and can dig slightly into the ground and fill itself simultaneously. As the hauling rope may be of any convenient length, a drag-line excavator has a wide range of action and can be used on slopes as well as on level ground. Drag-line excavators are not seriously affected by water or floods, and they can often work under conditions which would be unsuitable for any other form of mechanical excavator. This type of excavator is more fully described in connection with the working of loose sand deposits (p. 282).

Steam navvies are the cheapest means of excavating a thick overburden. They work most efficiently in loose material which is sufficiently thick to allow the shovel to make a cut throughout the greater part of its stroke, as steam navvies are not usually economical when they cut or dig during only a small fraction of the stroke. These machines are further described in connection with the working of loose sand deposits (p. 283).

Grab excavators are similar in many respects to a steam navvy, but instead of the bucket being forced into the material by means of a powerful arm or boom, a " grab " or " clam-shell " bucket is suspended from the end of the jib, and as it drops on to the ground it digs into the latter. On tightening the appropriate rope, the grab is filled, closed, and hauled up. The crane then revolves, and eventually the contents of the grab are discharged into a truck or wagon. Grabs are dealt with more fully in the section on working loose sand deposits (p. 287).

Ladder excavators are a modification of a well-known device known as a bucket elevator, and consist essentially of an endless belt to which is attached a series of buckets, each provided with a digging or cutting edge. They are more fully described in the section on working loose sand deposits (p. 290).

Explosives may be used for loosening rocky or other hard

overburden, and are employed in a manner similar to that usc prior to excavating hard sand roeks (p. 295). The loosened material is afterwards loaded by one of the applianees described above.

The **cost of removing overburden** and delivering it into wagons may be estimated roughly from the following figures:

Hand shovel and tipping wagon	15d. per cu. yd.
Steam navvy and wagons hauled by small engine . .	8d. ,,
Steam navvy and stripping conveyor returning overburden to disused workings	4d. ,,
Drag-line scraper (to loading platform only)	4d. ,,
Hydraulic stripping	2d. ,,

These figures are quite general in character, and have to be modified greatly before they ean be applied to some quarries.

The **disposal of the overburden** is a matter to which much thought should be given, because the removal of the material at a later date will add unnecessarily to the cost of working. This is a precaution whieh ought obviously to be taken by all quarrymen, yet it is surprising to find how often the overburden is tipped on valuable deposits whieh will be required at some future date.

In selecting a tip or dump, eare should be taken that (i.) the material plaeed on it can do no harm, and (ii.) it will not in any way interfere with tho future development of the works.

Sometimes it pays to carry the " stripping " to a natural valley, hollow, or swamp which will be more useful if filled, but usually the best place for the overburden is well behind or well to one side of the works or between the works and the quarry face.

For conveying the stripped material to the tip, wheelbarrows, wagons, or conveyor belts are used, but occasionally an overhead ropeway is employed. Wheelbarrows are the slowest and most expensive, except for very small quantities; conveyor belts are cheapest if the quantity to be conveyed is sufficient to justify their instalment and the distance is not too great. For longer distances, the choice between wagons and a ropeway must largely depend on local conditions.

Where a wide tip is required to be made by means of a ropeway, the use of rocking towers at either end of the rope may be an advantage. An arrangement of this kind—known as the Harrington rocking cableway—is supplied by the Railway and Industrial Engineering Co., Greenburg, Pa., U.S.A. (See also Chapter XI.)

Working Deposits of Loose Sand

The commonest method of working deposits of loose sand in this country is by hand, as most of the pits are comparatively small and hand labour is perhaps the most economical means of getting the sand. The material is dug in practically the same manner as has been described for removing the overburden (p. 278). The plough and scraper (p. 279) may sometimes be employed, though its use is somewhat rare.

Where the sand is to be removed on a sufficiently large scale, it is preferable to employ mechanical excavators, the particular type used depending on the nature of the deposit and the methods by which it can be worked.

Scoops are not used as extensively as they might be in quarries, because they are insufficiently known, particularly in Great Britain. As the work to be done by them is very rough and heavy, scoops must, of course, be correspondingly strong, and the hauling or pushing mechanism must be sufficiently powerful. The scoops used are of two types: (i.) scoops hauled by a rope and known as "drag-line excavators"; (ii.) scoops pushed into the material and either lifted and moved away or so arranged that the material is forced on to an endless belt at the back of the scoop and is thereby removed. The buckets or dippers attached to steam navvies or ladder excavators may, of course, be regarded as scoops, but it is more convenient to exclude them, as they are described later.

Drag-line excavators are sometimes quite satisfactory for excavating loose deposits. As previously mentioned, they consist of one or more buckets with a cutting or scarifying edge, which are dragged

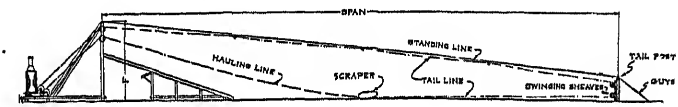


FIG. 28.—Drag-line excavator.

over the ground by a rope and so scrape up a load of the material, the amount depending on the size of the bucket. Drag-line excavators are of two types: (i.) those in which the skip is hung from the jib of a crane and is hauled towards the body of the crane; and (ii.) those in which the skip is operated by a ropeway. The latter have far greater range, though a skilled man operating the first type can swing the skip 30 ft. or more beyond the end of the jib.

In both types of drag-line excavators a high speed of operation and ample digging power are the most important factors; flimsy apparatus is useless in this type of excavator.

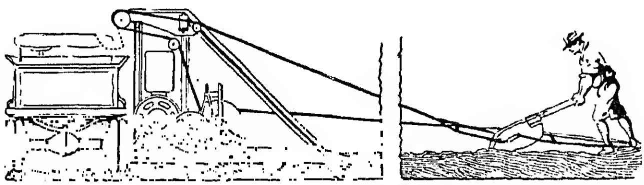
A drag-line excavator operated from a ropeway (Fig. 28) is very popular in the United States, and by its means the sand can be excavated, elevated, conveyed to the plant, and dumped in what is practically one continuous operation.

Pusher-scoops are very useful for beds less than 3 ft. thick. They are self-propelled and can work their way through a mass of sand at the rate of 70 ft. per minute, moving a maximum weight of a ton per minute and dealing with blocks up to 9 cwt. each. They have not been used to any great extent in England, but the Myers-Whaley shovelling machine has met with great success in some quarries in the United States. One of these machines, requiring three men—a driver, a wagon coupler, and a helper—will do as much

work as twenty men with hand tools. The front of the shovel is so designed that it will reach 10 ft. to either side from the centre of the track. The machine requires 20 h.p. to drive it at full capacity; either compressed air or electricity may be used.

The use of a tractor for working a scoop offers considerable possibilities and is worth consideration in some quarries. The chief difficulty is that where the ground is so rough as to make a scoop practicable, it will soon wear out the tractor.

In an American machine, made by the Pawling and Harnischfeger Co., of Milwaukee, U.S.A., a boom is fitted which, when digging, is horizontal, the scoop running along it away from the tractor. When the bucket is full, the boom is raised and the machine turned, so as to tip the material into a truck or other receiver. Another useful scoop is the Rapid-digger Co.'s machine (Fig. 29), which is hauled and discharged mechanically, but is guided through the material by hand. This machine can be quickly moved about under its own power; it has a reasonably long working range and



Rapid-digger Co., New Jersey.

Fig. 29.—Rapid-digger scoop.

is, under favourable conditions, equivalent to the work of ten to fifteen men.

Steam navvies (Fig. 30) are very satisfactory for digging sands which are sufficiently friable, and if there is a sufficient thickness of material to work upon. For effective work with a steam navvy, however, the quarry must have a long face, with a terrace or bench of sufficient width to accommodate the navvy and two sets of lines, for the wagons and the whole of the material must be dealt with "as it comes." If much sorting is necessary—as when fissures or intercalations filled with clay or other materials occur—a steam navvy is of little use. For excavating or lifting shattered or broken stone, a steam navvy should be of suitable design and with a long range. Some of the most suitable ones will "clean up a quarry floor" as well as load from a high bank. In a properly arranged quarry of sufficient size to keep a steam navvy fully occupied, this machine will be found to work remarkably cheaply, for excavating either sand or a shattered rock, or for picking up broken stone, provided it has enough work to do.

To work efficiently, a steam navvy must be able to work continuously for eight hours per day during five days per week,

and continual maintenance, so that adequate platforms, steps, or ladders should be provided, from which oiling, adjustments, or repairs may be safely performed so as to prevent the repair men from being exposed to unnecessary risks of falling.

Most steam navvies are now fitted with an over-hoist or over-travel stop that automatically arrests the upward travel of the boom and the bucket, if the operator fails to stop the machine at the proper time. Some drivers supply the power and calmly wait for the load to come in contact with the over-travel release, thus stopping the machine automatically. The danger of such an operation is evident, and it should be a matter of strict discipline to see that it is not made a regular practice.

Every steam navvy requires to be lubricated in order to prevent wear from friction and destruction from rust. The lubrication of the cables is sometimes accomplished by a man standing on the trolley, who applies the grease as the cable is wound up. Sometimes the cable is all wound up and the top half of the drum properly greased. The bottom half is then greased after the drum has made half a revolution to bring the ungreased cable into an upward position. Another greasing device, attached to the top of the hoisting block, consists of a brush or collar made of soft wicking, which surrounds the cable and is connected with the tank in such a way that the rope in passing through the collar or brush becomes properly lubricated throughout its entire length.

A steam navvy requires a small gang of men, and when worked properly and well supplied with wagons it can load a great mass of material in a day. Efficient service depends on strong mechanical construction, adequate care and management by a skilled worker. Inefficiency usually results from inadequate supply of wagons for the removal of the loaded material rather than from improper handling of the steam navvy itself.

While the first cost of a steam navvy is high, with proper care the cost of maintenance is not excessive, and where the surface is fairly uniform and level a steam navvy is probably the best device for removing any sufficiently large quantity of material. In fact, four or five men with a steam navvy can load as much sandstone as forty-five men by hand methods.

For excavating rocky material, a large and powerful navvy is needed, the "railroad" type being preferable, but for softer material and for smaller outputs, a revolving steam navvy is often more advantageous, especially if it is mounted on wheels or "caterpillars," so as to travel forward under its own power. As the smaller steam navvies are not as strong as the larger ones, care should be taken to select a machine of ample strength for its intended purpose. Thus, it may be more profitable to purchase a machine of much greater strength than is needed for the stripping, if it can be used later for loading the sand or stone.

Although usually known as "steam" navvies, these machines may be driven electrically, and in many quarries the latter is

preferable as it saves the cost of hauling the coal to the quarry face.

The saving effected by using a steam navvy as compared with hand labour depends on the proportion of the working day during which the machine is actually digging, and this, in turn, depends on there being a sufficient number of wagons or cars ready to receive the excavated material. The wagons or cars may often be run along the top of the bank of a shallow cut and kept moving in a continuous line, except for the delay caused by turning and then backing them up to the navvy, when this is necessary.

Among the more important precautions in working steam navvies are the following: The boiler must be properly cared for and not fired too rapidly when it is full of cold water. It is important to clean the flues once a week or the boiler will not steam properly, and to blow off sufficient water once a day when the boiler is at about 60 lb. pressure. The boiler should be thoroughly cleaned once a fortnight. The cylinder cocks on the engine must be opened before starting, after standing for some time; failure to do this may result in a loose piston or the knocking out of the cylinder head. When the engine is warm, the cocks are closed. It is desirable to open all the drain cocks and to drain the lubricator before leaving the engine for the night, otherwise in cold weather the water in the engine may be frozen solid by morning.

To prevent accidents due to explosives being prematurely fired by sparks from a steam navvy, the following additional precautions should be taken: Before loading is begun, the steam navvy and locomotive should be withdrawn from the face of the quarry to such a distance that no sparks from them could, under any circumstances, be carried to the explosive in the holes, or on the ground above or around. If there is any danger from sparks or cinders, a canopy should be provided which will protect the explosive from flying sparks. A covered hopper may be used for black blasting powder.

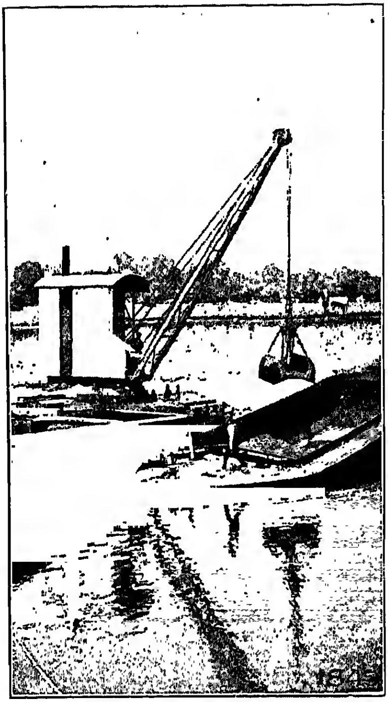
Where an unexploded charge is uncovered by the steam navvy, operations should cease until the explosive has been recovered and removed to a safe distance.

Grabs (Fig. 31) are also very useful for working loose deposits, as they serve not only as excavators but also as loaders. A grab consists of a special device consisting of a container, the bottom of which is formed of two jaws meeting at the centre. The grab is hung from the rope or chain of a crane. The jaws are opened and the grab is lowered rapidly on to the sand or stones to be lifted. By its impact the grab penetrates into the material, and when withdrawn its jaws close and the grab carries with it a load (up to about 15 cwt.) of material. A pull on a rope reopens the jaws and the grab discharges its contents.

Grabs are not very suitable for loose dry sand, as so much of it leaks out before the grab discharges its load. They are excellent for gravel, small stones, sand, and clay.

A serious objection to grabs is that they will not remove the whole of the broken sandstone from a floor and leave the latter clean, but they are excellent for removing large quantities of loose material if it is not too fine in character, the last portions being loaded by hand.

The cranes used for grabs must be movable, so that they can be transported from place to place, and are preferably self-propelling. It is a great convenience if a locomotive or travelling crane is fitted with a revolving mechanism, so that the crane may be turned in every direction.



Priestman Bros., Hull.

FIG. 31.—Grab discharging sand.

Electric cranes are in every way satisfactory when the cost of electric current is not too high; they work rapidly, and yet are very economical in regard to power, but they cost more in the first instance and also for upkeep and repair. The motors on an electric crane must be of the best quality and of robust construction; a continuous current series-wound motor is better than a shunt-wound one or one with an alternating current, though the latter are regarded with satisfaction in some quarries.

The stability of the crane in use is a matter of greatest importance, as more serious crane accidents are due to the crane being used outside its range of stability than to any other cause. The necessary stability is obtained in stationary cranes by weighted fixed sleepers, to which the masts and guys are attached, and, in some cases, by a counterpoise so placed as to prevent the crane falling over in the direction of the load. In arranging the stability of such cranes, care must be taken to provide for sudden loads not strictly central to the crane, whereby the greater part of the load is thrown on to one "leg" or guy, or the stress is applied chiefly to one sleeper instead of equally to all. A common, and usually safe, practice is to use on each sleeper a ballast-weight equal to at least twice the load to be lifted.

In locomotive and revolving cranes, the engine and boiler are

usually placed as a counterpoise, and in selecting a crane of either of these types, care should be taken to see that the balance is properly maintained at all reasonable positions of the crane and maximum load. Wedges and rail clamps are frequently used for locomotive cranes, and are quite satisfactory within their legitimate limits, but should not be relied upon for exceptionally heavy service.

In revolving a locomotive crane, there is always a tendency to cause it to fall over by applying it to a load which is beyond its normal radius, or on one side of the jib, or by swinging the crane round in such a position as to place the load outside the normal radius, namely the horizontal distance from the centre of gravity of the suspended load to the axis of rotation of the crane; as, for example, the horizontal distance between the centres of the hoisting hook and the centre pin of the crane. Another common cause of mishaps is due to keeping the jib at a specified radius, but dragging the grab from a point beyond this radius. The capacities of the crane given on the identification plate apply only when the load is directly underneath the hoisting block. Moreover, they are the maxima allowable, and care must be taken not to overstrain the crane by exceeding them.

Many of the motions of hoisting, turning, travelling, and varying the radius may be effected together, and thereby much time may be saved. The following matters should be considered in working locomotive cranes with grabs:

(*a*) Whether the load to be lifted is too great.
(*b*) The possibility of the grab being caught between stones and so held by them.
(*c*) The radius at which the load is operated; the hoisting line should be vertical when lifting a load. This fact explains the importance and advantage of a derrick crane in which the jib can be raised or lowered so as to vary the radius to suit the positions of the load.
(*d*) The proper distribution of the ballast or counterpoise.
(*e*) The wedges or clamps must be properly placed.
(*f*) The turning must be as rapid as possible so as not to waste time, yet must not be excessive, or an accident may ensue.
(*g*) Checking the load very suddenly by the brake is always dangerous.
(*h*) The condition of the track—whether level, with a high elevation on one side, or curved—must be considered, as it has a great effect on the movement of the crane and on the loads which it is safe to move.
(*i*) Whether the load is to be lifted with the main hoist-block or with a single line. This involves a careful consideration of the load and the radius throughout the whole movement.

The foregoing remarks must not be taken as indicating that

the crane and grab form a delicate and risky machine, for that is not the case; at the same time, much of the difference between efficient and inefficient working is usually due to a number of simple, yet often neglected factors, such as those mentioned.

Carelessness in fixing and working cranes has been the prime cause of many accidents, and, for this reason, care should be taken to employ only skilled crane drivers and to give them every facility for doing their work properly.

Cranes are provided with either chains or wire ropes. Corrosion is not so serious with a chain as with a rope, and the durability is much greater, but, as chains are both costly and heavy, wire ropes are extensively used, and if well cared for are quite satisfactory. In estimating the strength of a chain, it must be remembered that this depends chiefly on the thickness of the metal and not on the size of the link.

Whilst crane manufacturers can usually be relied upon to provide suitable pulleys, it sometimes happens that when a crane is purchased second-hand, or a broken pulley is replaced by a new one, the pulley or winding drum is of too small a diameter, and so puts too severe a strain on the rope. This may appear a matter of small importance, but lack of attention to it has been the cause of several accidents.

In addition to suspending a grab from a crane, it may be suspended from a cable and operated by a single winding drum. The grab digs into the material, picks up a load, is hoisted and then conveyed along the cableway track, its load drops automatically, and the grab then returns to the starting-point for the next load, always under the control of the hoisting engineer.

Ladder excavators (Fig. 32) are not used to any great extent in this country, but they are very useful and may profitably be applied in cases where there is a demand for an exceptionally large output—at least 3000 tons per week. As previously mentioned, they consist of an endless belt to which is attached a series of buckets, each provided with a digging or cutting edge. The buckets are placed at a suitable angle to the surface of the material to be excavated, and, as the belt rotates, each bucket digs into the material, is filled, carried forward, and eventually discharged into suitable wagons. If the belt is of sufficient length and the excavated material is overburden or "spoil," it may be carried sufficiently far to be tipped at the back of the workings, where it will do no harm, and the expense of wagons may then be saved. Ladder excavators can be worked satisfactorily on an almost horizontal surface. The driving and supporting machinery may be either above or below the material to be excavated, the former position being usually preferred.

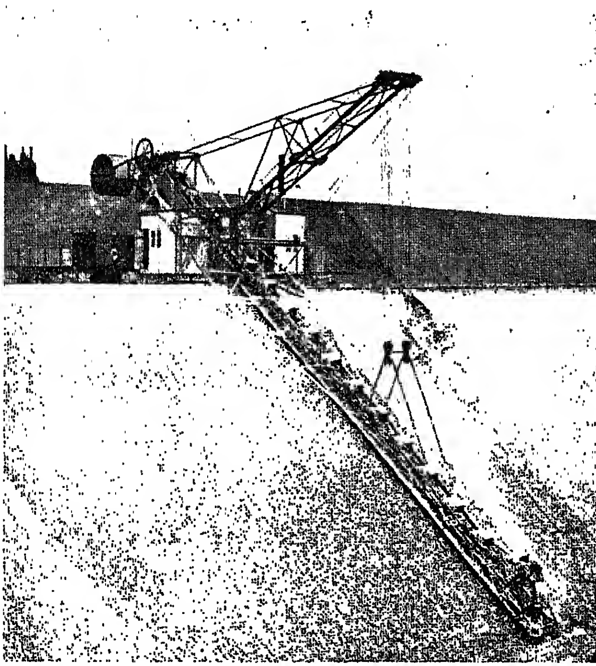
Hydraulicking.—Where the conditions permit, the sand may be removed by the use of a powerful jet of water, as in removing overburden (p. 278).

The water, under a head of 100-600 ft. or more, is supplied through a pipe with a nozzle (Fig. 33) 2-10 in. diameter, according

to the amount of water required. The amount of water delivered per minute may be calculated from the following formula, due to J. J. Gerrard:

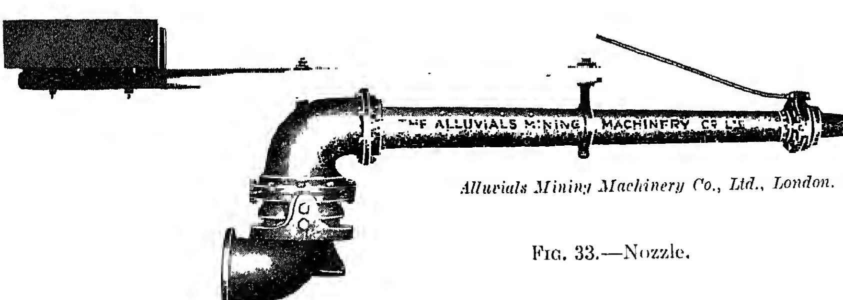
$$\text{Water delivered in cu. ft. per min.} = 3{\cdot}75d\sqrt{P},$$

where d is the diameter of the nozzle in inches and P is the pressure in lbs. per sq. in. P is also the effective head in feet $\times 0{\cdot}4326$.



F. L. Smidth & Co., Ltd., London.

Fig. 32.—Ladder excavator.



Alluvials Mining Machinery Co., Ltd., London.

Fig. 33.—Nozzle.

Table LXI. shows the amount of material removed in twenty-four hours by hydraulicking, using nozzles of varying sizes.

TABLE LXI.—MATERIAL REMOVED BY HYDRAULICKING (per day)

Effective Head in feet.	Size of Nozzle. Inches.	Flow in cu. ft. per Min.	Approximate Output in 24 Hours in cu. yds.
100		104·88	160
200	2	148·32	230
300		181·61	280
400		209·82	320
100		420·06	650
200	4	594·00	930
300		727·56	1130
400		840·12	1300
100		944·58	1460
200	6	1335·72	2000
300		1634·08	2540
400		1889·16	2920
100		1679·82	2600
200	8	2375·46	3600
300		2909·58	4500
400		3239·70	5300
100		2624	4080
200	10	3711	5760
300		4545	7050
400		5248	8140

Hydraulicking is employed in some sand-pits in America; it is also largely used for placer-mining in connection with metalliferous sands. Thus, gold-bearing sand deposits are frequently worked by hydraulicking, the material being washed on to a grating or grizzly which separates the larger stones; the sand then being conducted through channels to the separating tables, where any gold present is recovered. Tin-bearing gravels, diamond gravels, and other placer deposits are also worked by hydraulicking in the same manner.

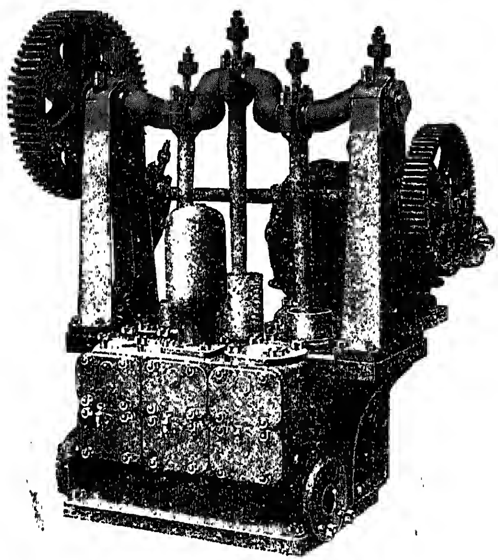
Dredging.—In some cases the sand-bed lies below water-level and it is necessary to dredge in order to recover the sand. The best conditions for dredging are (*a*) soft even bedrock, (*b*) absence of boulders, (*c*) absence of any great amount of clay, (*d*) a depth of water at least 50 miner's inches,[1] (*e*) absence of floods.

The most suitable method for dredging such a material depends largely on its situation, one of the following being usually adopted: (i.) the bulk of the apparatus may be on dry land and the dredging

[1] A miner's inch is the quantity of water passing through a horizontal slit 1 in. wide and 24 in. long with water in a reservoir standing 6 in. above the hole. It is equivalent to 2274 cu. ft. per 24 hours.

effected by extending a dredger-bucket or scoop and drawing it back again to land; and (ii.) the apparatus may be mounted on a boat of some kind; when the hold is full, the boat is brought to the shore and emptied.

Where the conditions permit and the water is not too deep, sand may be dredged from the bottom of a lake by means of a drag-line excavator of the Sauerman or similar type (p. 282), the supports being erected on the opposite shores of the lake and the material drawn up and dumped into bins on the works. Where this is not possible a flat-bottomed dredge boat is employed; this is fitted



J. Evans & Sons, Ltd., Wolverhampton.

FIG. 34.—Plunger pump.

with a bucket-dredger or other means for drawing up the sand from the bottom of the lake.

Bucket-dredgers mounted on boats or rafts are employed for recovering sand from below water-level to a depth not exceeding about 40 ft. The buckets vary in number and size, some of the largest having a capacity of 16 cu. ft. The cost of working such a bucket-dredger varies with the conditions, but is generally between 1d. and 8½d. per cu. yd.

Table LXII. shows the capacity of bucket-dredges of various sizes.

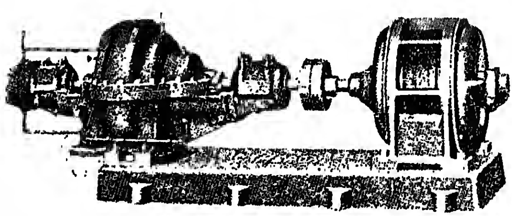
Another very useful and convenient appliance is a sand-pump of the plunger (Fig. 34) or the centrifugal (Fig. 35) type. The

TABLE LXII.—OUTPUT OF BUCKET-DREDGES

Size of Buckets, cu. ft.	Horse-power.	Maximum Digging Depth below Water Line, in ft.	Output in cu. yds. per Month.
3	180	36	48,000- 60,000
5	220	36	90,000-110,000
7	300	35	110,000-150,000
8½	560*	48	150,000-185,000
13	415	40	250,000-280,000

* This includes 100 h.p. for pump for two monitors.

suction pipe has attached to it a cutting or scarifying edge, which breaks up the material and enables it to be more easily drawn in by the pump. The material is conveyed from the pump to the shore in a segmental pipe line which is usually hung from pontoons, placed at intervals between the boat and the shore. The dredging boat may be controlled by ropes on shore. At the shore end of the pipe line the mixture of sand and water is discharged on to a large pile, the water running off and leaving the sand fairly dry.



Ingersoll-Rand Co., Ltd., London.

FIG. 35.—Centrifugal pump.

The sand can then be lifted by means of a grab or other loading device into trucks or bins. In America, the sides of one small lake which consist of sand and gravel are dislodged by a powerful stream of water in the same manner as for hydraulicking overburden, and the material washed down is sucked up by means of a powerful centrifugal pump.

Some of the Belgian silica sand is obtained by dredging, as are many of the sands in the United States.

QUARRYING SAND-ROCKS

The various methods used for removing the stone and delivering it either to the works or to trucks, etc., may be classified under two main heads: Quarrying and Mining. In the former the overburden is removed by one of the methods previously described,

and the material is thus made accessible in an open working; whilst in mining the overburden remains *in situ* and the material is cut from beneath it, the only portions of the overburden to be removed being that which is necessary to secure a good "roof" to the mining galleries.

In most cases, sand-rocks are only mined when they occur in conjunction with some other, possibly more profitable, material. Thus, ganister is mined, as it occurs in conjunction with coal seams which are worked at the same time, and the two kinds of material are removed by means of the same shaft. It seldom pays to open mines specially for the extraction of sand-rocks, as the cost of making the shaft is usually prohibitive.

In order to remove the sandstone from an open quarry, the first step, after the removal of the overburden, consists in loosening the sand-forming material, so that it may be removed to the wagons, etc., used to convey it to its destination.

Loosening the Material.—The portions of the rock required for use must be loosened and separated from the main mass before they can be subjected to further treatment. For this purpose, picks, wedges, crowbars, and hammers may be used in some localities, but unless the rock is very "shattered," or only small quantities are required, it is better to loosen it by means of explosives.

Blasting.—Boreholes are drilled in the rock at suitable distances from its face and from each other and a charge of explosive is placed in each hole. On exploding the charge, the surrounding mass of rock is shattered and loosened, so that the greater part of it can be placed in wagons or on wheelbarrows and taken away. The largest blocks may be broken with a hammer or with a small charge of explosive.

It is important that the material should be removed in a wisely systematic manner so as to keep the quarry and working face in a state convenient for working, otherwise the future development of the quarry may be seriously hampered or even stopped.

Although many rules have been proposed in order to increase the efficiency of the blasting operations, it is still a fact that better results will be obtained by an experienced, intelligent quarryman working without any conscious adherence to rules than those which follow from the efforts of some less experienced men who appear to follow rules closely. In deciding the best position for the charges of explosive, as well as the amount of each charge, judgment is more important than any rules, though the latter are valuable as rough guides to general practice and ought not to be disregarded without reason. The wise quarryman in charge of blasting operations will, in fact, regard rules as the summary of other men's experience, rather than as inflexible commands. In short, the precise method of working should depend on local conditions, and as these differ in each quarry only a general idea can be given here.

The *position of the boreholes* should be selected in accordance with the natural joints or divisional planes of the stone, as in most cases these will determine the limit of the effect of the explosive by providing a vent through which the explosive force will escape. For this reason, it is obviously wise to drill across the horizontal or inclined joints or planes of fracture and not along them. As the greatest effect will be obtained if the explosive meets with an equal resistance in every direction, this position should be chosen where such an effect is desired. Hence, the depth of the borehole should usually be equal to its horizontal distance from the face, though much will depend on the structure of the stone, the number, size, and position of the joints in the interior of the rock, and the tendency of the stone to break along particular lines of weakness. When very large quantities of rock are to be shattered at once by means of a single, heavy charge, it is particularly necessary to find a part of the rock of great uniformity, as if this is not done there will be a serious waste of explosives owing to much of its force being dissipated along joints, fissures, and cleavage planes.

It is often advantageous to prepare a number of boreholes and to explode them all at the same time, as the effect is thereby increased if the holes are not too far apart. It is often difficult to decide whether a single large charge—constituting a " chamber charge " or " mine "—is preferable to a series of boreholes fired simultaneously.

The *size of the boreholes* depends on the explosives used; with gunpowder, holes 1 in. or 1¼ in. diameter are usual, but for dynamite smaller holes may be used. Very narrow holes are not advisable, however, as they are difficult to charge properly. Boreholes more than 3 ft. deep are usually 2 in. or more in diameter for the upper part and 1 in. diameter for the last 3 ft. The holes should be truly circular and cleanly bored. Before use their exact size and depth should be tested by inserting a suitable testing-rod.

The depth of the borehole should not extend to a horizontal joint or plane of fracture. Where there are two free faces to the rock to be blasted, a horizontal line from the borehole to the nearest face should be about two-thirds of the depth of the borehole; in some (unusual) circumstances very deep boreholes relatively near the face would be justifiable.

The toughness of the rock is also an important factor, as a tough rock with few seams or bed planes tends to break into large cubical pieces requiring excessive secondary blasting. The best method of dealing with such rock can usually be determined only by experience, though much may be done by varying the diameter and spacing of the drill holes, or the amount and nature of the explosive.

An examination of any quarry where an excessive amount of secondary blasting of the large loosened blocks is required will show that it is largely dependent on the skill employed in the primary blasting. For instance, an improper arrangement of the

drill holes, imperfect balancing of charges, or the use of too powerful or too weak an explosive may result in a very inefficient blast and, as a consequence, the loading may be greatly hampered, particularly where many large charges are fired simultaneously in deep churn-drill holes, the mass of rock thrown down occupying the fillers for several weeks or even months. If the rock is imperfectly shattered or improperly thrown down, excessive secondary blasting may be required and the filling of the wagons may be both slow and difficult. On this account it is a false economy, both of money and labour, to place inexperienced men in charge of the blasting.

Drilling the boreholes is a matter requiring considerable skill and care, as a faulty hole may cause a serious accident. The boreholes may be made in several different ways: (i.) by hand, (ii.) by augers or screw drills turned by hand power, with or without a mechanical feeding appliance, (iii.) by rotary power-drills, (iv.) by percussion power-drills, and (v.) well-drills. The height of the face, the depth and diameter of the holes, the hardness of the rock, cleavage and wetness of strata, the necessity or advantage of speed, and other conditions, vary so much that there is no single system of drilling which can be used exclusively to the best advantage in all cases.

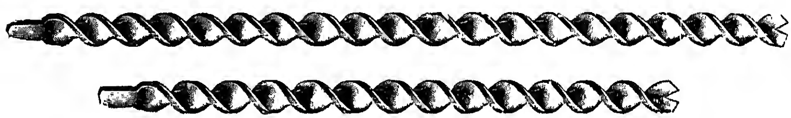
When the amount of drilling is sufficiently large, the cheapest method is by means of a pneumatic hammer, a wave-transmission device, or other power-driven appliance; but where power is not available the much slower hand-drills are used. The old hand-drill or jumper will always be of service where it is difficult to supply air or steam, especially for small holes and to depths not exceeding 15 ft. The tools required for this work are a 6-lb. sledge-hammer and three drills or spuds, varying in length from 3 to 4 ft. for the shortest, up to 10-12 ft. for the longest. It is necessary to have these lengths to suit the convenience of the men as the hole deepens. The drills are of tool steel $\frac{7}{8}$-$1\frac{1}{4}$ in. in diameter; the lower end is sometimes drawn out to a fan-shaped bit or cutting point. A bucket of water, a dipper, a brush or "swab," and a scraper for cleaning the drill are also needed. The drillers usually provide their own swabs by cutting a young sapling (preferably of hickory) an inch or so in diameter and about 10 ft. long; prior to using it one end of this stick is beaten with the sledge-hammer so as to fray it for a length of 6-8 in. and to convert it into a rough brush.

In drilling a vertical hole by hand, one man uses the sledge-hammer, another holds the shortest drill at the point selected for boring. The man with the sledge-hammer (called the striker) strikes the drill with quick sharp blows, and the driller raises the drill a short distance between each blow of the sledge and, during the same interval, twists the drill through an angle of 30-40 degrees. Each twelve blows, therefore, cut the bottom of the hole over its entire area, creating numerous small chips of loosened rock. This procedure is continued until several inches of rock have been

drilled. A little water is now poured down the hole and the brush end of the swab inserted, and after moving it up and down several times, it is withdrawn laden with the newly made mud. The swab is then given a sharp blow or rap over a block of wood or a stone, thus freeing it from the accumulations. A little more water is then added and the work proceeds until a hole of the desired depth is reached, usually not exceeding 10 or 12 ft. The hole is then dried and cleaned out as carefully as possible by pouring down a handful of dry dust and withdrawing it in a spoon or scraper, this "dusting" being repeated as often as necessary. In wet rocks, or those permeated by water-bearing seams, this "drying-out" is very difficult; it may be avoided by using a cartridge of oiled or soaped paper, which will slip down the hole quickly and permit a shot to be fired before the water soaks through the paper.

Drilling by hand, using a $1\frac{1}{4}$-in. drill in fairly hard stone, costs 17d.-23d. per foot. Three men will not usually drill more than 15 ft. per day with a $1\frac{1}{4}$-in. drill.

An *auger or screw drill* (Fig. 36) is limited to rocks of about



Hardy Patent Pick Co., Ltd., Sheffield.

Fig. 36.—Auger drills.

the hardness of coal and is not really applicable to hard rocks. The simplest form of this drill is fitted with a double brace or handle devised for rotating the auger, the man using both his hands to maintain the motion, and his chest to supply the pressure of the drill against the rock. This simple form is only applicable to very soft materials; for harder rocks, a frame is fixed between the floor of the quarry or mine and some point above, in the face of the rocks or in the roof of the mine, and is braced in position by screws and guys. The auger is mounted on the end of a long screw or threaded steel bar, which is passed through a nut or female screw fastened in the frame. By turning the screw, it feeds itself forward at the rate of about $\frac{1}{8}$ in. per revolution. The turning is effected by a crank or handle on the end of the screw or by the intervention of gears with two or three different rates of motion, if the rock to be drilled is fairly hard; the power is supplied by the driller himself. A man will drill a 3-ft. hole $1\frac{3}{4}$-2 in. diameter in ordinary rock in twenty to thirty minutes, and often much quicker.

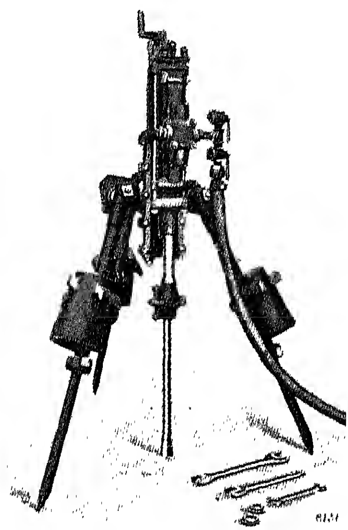
Auger or screw drills are of good service in mines where the roof or floor offers facilities for fixing them in position. They will bore holes at almost any angle, but most easily when horizontal. They are used, but not so handily, along the floor of a bank in an inclined position, and for making horizontal holes or holes inclined

downwards. They are seldom satisfactory for boring vertical holes in open workings.

Rotary power-drills and *percussion power-drills* are only used in the larger works, though a rotating drill driven by compressed air will bore small holes faster than any other drill. Part of the exhaust from these little machines can be turned down through the hollow drill to blow the cuttings from the holes. Ordinarily, 1½-in. holes, not more than 6 ft. in depth, are the largest which can be made by the smaller-sized hammer-rotating drills. For the best results these drills require about 50 cu. ft. of free air per minute, under a pressure of 80-100 lb. per square inch. Rotating hammer drills are especially valuable where there are so many large pieces to be broken.

Percussion drills include those operated by counterpoise weights, electricity, or other simple source of power, pneumatic hammers and drills operated by compressed air, and the drills operated by compressed liquids (wave-transmission).

Steam (Fig. 37) or air tripod drills are suitable for vertical, horizontal, or inclined boreholes up to 4 in. diameter. Depths greater than 20 ft. can be reached, but the long rods required for deeper holes are difficult to handle. Under good conditions one of these drills will bore a vertical hole 60-90 ft. deep, or a horizontal hole 20-50 ft. in length per day. For drilling fairly hard rocks, a chisel or drill with a fairly acute angle should be used, but if the stone is soft, a drill of wide angle should be used, as an acute drill will be jammed in soft rock because the drill penetrates faster than the loose material can be cleared away.



Ingersoll-Rand Co., Ltd., London

FIG. 37.—Tripod drill.

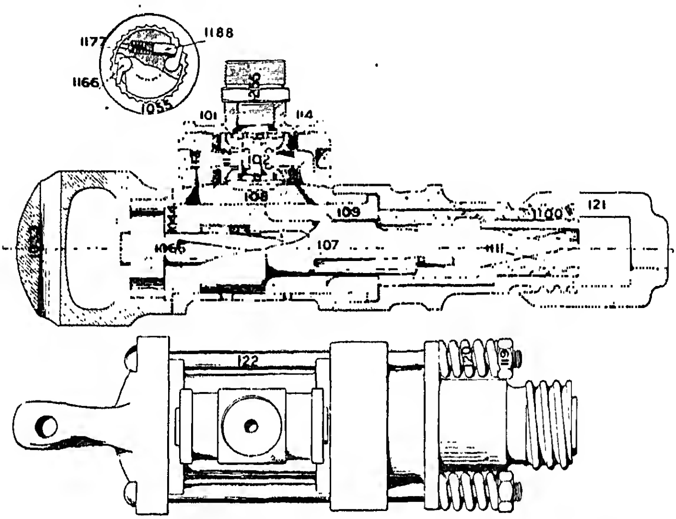
For rough ground which will not permit the use of a well drill or ledge-blasting a tripod drill may be found very satisfactory. Tripod drills require two men each, a runner and a helper, though in some circumstances one helper is deemed sufficient for two drills.

Pneumatic hammer drills (Fig. 38) are very useful portable machines. They consist of a cylinder fitted with a plunger having a stroke of about ½ in. Attached to the plunger is a slide valve, so arranged that when the plunger is at one end of the cylinder compressed air enters behind it and drives it forward to the other end, at the same time closing one valve and opening another which

reverses the motion. At each forward motion the plunger strikes the drill head and drives it into the rock. Such drills are capable of 800-1000 blows per minute and will drill very rapidly. Many different patterns have been patented, but they all work on the same general principle. They can be operated by one man and require less labour than tripod drills.

The power used in working percussion drills is usually steam or compressed air, but water (wave-transmission) offers great possibilities.

Air compressors (Fig. 39) are of three chief types: (*a*) the horizontal slow-speed, (*b*) the vertical quick-revolution, and (*c*) the



Hardy Patent Pick Co., Ltd., Sheffield.

FIG. 38.—Hammer drill.

turbo-compressor. The durability of type (*a*) and the ease with which it can be repaired and adjusted makes it popular, but it requires large foundations and buildings. The vertical quick-revolution type has the advantage over the horizontal type as regards the space occupied, but the general inaccessibility of its parts and the heavy cost of upkeep are against its wide adoption. The turbo-compressor is chiefly used for very large plants. The efficiency of the turbo-compressors has been greatly improved, but even yet it is questionable whether they are as efficient as reciprocating compressors. Moreover, in actual practice, compressors are often run much below their full load, and the efficiency of the reciprocator under these conditions is much higher than that of the turbo-compressor.

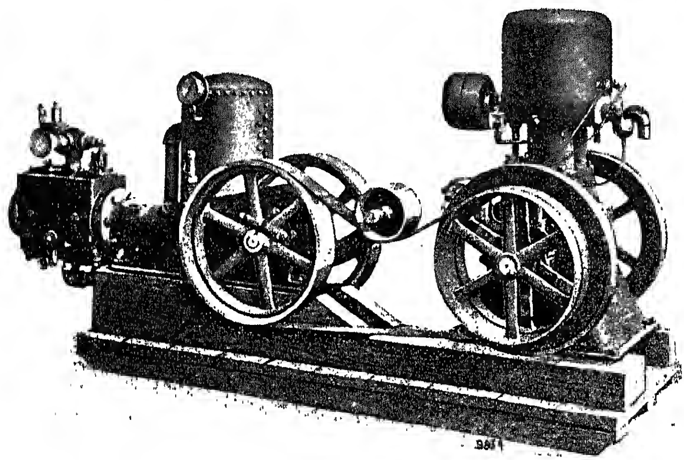
Full details of the construction of each type of compressor

need not be given here, as they can be readily obtained from the manufacturers. In selecting a compressor the following factors should be considered :

(i.) The primary power used for driving it must be reliable and efficient.

(ii.) The suction stroke of the compressor should, throughout its length, fill with air at atmospheric pressure.

(iii.) On the compression stroke there should be no loss of air as a result of the inlet valves closing too late, nor should there be any leakage back ; the whole contents of the cylinder, less



Ingersoll-Rand Co., Ltd., London.

FIG. 39.—Air compressor.

the minimum clearance, should be discharged through the outlet valves.

(iv.) The outlet or discharge should have an opening of ample area ; it should open automatically on the requisite pressure in the receiver being reached in the compression-cylinder, and the air should be discharged at a pressure as little above that in the receiver as possible, as an excess of pressure causes a rise in temperature with an increase in the volume, requiring a corresponding increase in the work necessary to compress and discharge the air.

(v.) The discharge valves should have sufficient width of seating to ensure their keeping quite tight, so that no loss may take place by a leakage back into the cylinder.

(vi.) The valves should be self-adjusting at all speeds and pressures.

(vii.) All valves and the piston should be easily accessible for examination and renewal.

(viii.) The compressor should have full volumetric efficiency.

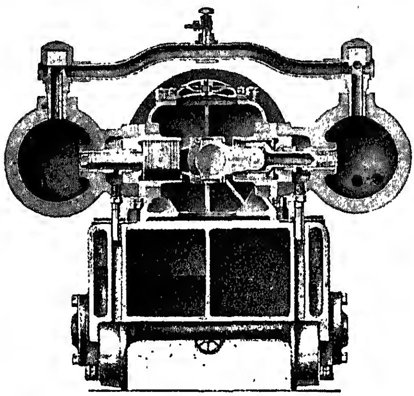
(ix.) Wear and tear should be reduced to a minimum.

(x.) An efficient unloader must be fitted.

(xi.) A good fly-wheel and an efficient governor are essential.

(xii.) In two-stage compression the efficiency depends upon the intercooler, which should keep the high stage intake air at the same temperature as the lower stage intake air, and air-cooled to within 20° F. of the temperature of the entering cold water. The supply of water for the intercooler should be $2\frac{1}{2}$ gallons per minute per 100 cu. ft. of free air; more water is an advantage if it is available.

(xiii.) The receiver should be placed within 40 ft. or 50 ft. of the compressors, its use being (1) to eliminate pulsation effect, (2) to minimise the frictional loss attending the flow of the air in the lines, (3) to serve as a reservoir, and (4) to cool the air and cause it to deposit its moisture.



W. H. Dorman & Co., Ltd., Stafford.

FIG 40.—Wave-power generator.

(xiv.) The receiver must be of ample size (one or more auxiliary receivers near to the face often effect a saving). By adopting a receiver of large capacity the compressors can run at a continuous speed—the pressure being retained for a longer period with greater power, and the periods of minimum demand are utilised by the compressors in filling up the receiver and increasing the efficiency of the plant.

Compressed liquids are chiefly used for the wave-transmission method invented by C. Constantinesco, and used in the machines supplied by W. H. Dorman & Co., Ltd., of Stafford (Fig. 40). Wave-transmission may be briefly described as a mode of conveying power by a series of impulses, imparted to a column or pipe line of fluid, usually water, by a very simple generator coupled to a steam engine or other prime mover. These impulses or waves travel at the same speed as sound and they can follow each other at any desired interval. The great advantage of wave-transmission as compared with compressed air is its economy of power, which in the end, of course, means a saving of cost. In working a rock drill, for example, wave-transmission delivers eight times as much power at the rock face as compressed air, with the same input of power. The difference represents, roughly speaking, a saving of 70 per cent in power.

There appears to be an enormous future for wave-transmission,

which will count as one of the big engineering advancements of the early twentieth century.

Explosives.—The explosives used in blasting sandstone, etc., are of various kinds, and considerable care and skill are needed in their selection. For very soft stones and merely for loosening large blocks, gunpowder or other relatively slow explosive applied in fairly large quantities is the best; but for hard stone which is to be reduced to small material an explosive containing dynamite, or one of the modern safety explosives, is more suitable. On the whole, dynamite and other high explosives are preferable where a heavy shattering effect is required.

The practice of drilling a hole, enlarging the base by first exploding in it a charge of gunpowder, and then filling the enlarged hole with a more powerful explosive, is economical, as it reduces the number of holes required, but it is accompanied by serious risks, especially if the first charge has not been completely exploded.

The amount of explosive required depends on (1) the kind of explosive used, (2) the depth of the borehole, (3) the line of least resistance. It is roughly inversely proportional to the number of free faces of the rock to be blasted. Thus, a rock with two free faces will require only half the explosive needed for a rock with only one free face; a rock with six free faces will require only one-sixth as much explosive, and so on; another useful rule in calculating the amount of explosive required is to divide the cube of the depth of the borehole by 25; the quotient is equal to the number of pounds of gunpowder to be used in each charge. Thus, if the borehole is 3 ft. deep, the cube is 27, and this divided by 25 gives 1·08, so that rather more than 1 lb. of gunpowder should be used. For very large blasts, the maximum amount of gunpowder to be used is about 1 lb. for each 3 tons of rock, but for some rocks as little as 2 oz. per ton of rock may suffice. In many instances there is a serious waste of explosives, due partly to using too much in each charge and partly to wrong distribution of the boreholes. The object in quarrying is to rupture and loosen the rock, not to hurl it a great distance; hence, only enough should be used to accomplish what is required. Where much of the rock is thrown a great distance, it is evident that too large a charge was used. With very hard rocks it is difficult to avoid this kind of waste.

Charging the boreholes requires great care. When gunpowder is used, the hole should first be tested as to diameter and depth; it should then be wiped clean and dry with a cloth on the end of a rod. A little of the gunpowder is placed at the bottom of the hole by means of a zinc funnel, a piece of fuse [1] with a blasting-cap is inserted, the remainder of the charge is then poured into the hole, and a paper wad pressed on top of the charge by means of a wooden

[1] Electrical detonation is safer than the use of a fuse. Some quarry managers employ both a detonator and a fuse, in the hope that, if the former fails, the latter will explode the charge.

od. The hole is then filled gradually with air-dried clay, or fine lried sand, which is inserted in small quantities at a time and ammed tight after each insertion. The length of the fuse used nust be sufficient for it to project a suitable distance from the hole to permit safe ignition and escape before the explosion occurs. Sand appears to be preferable to clay as a packing material, as it requires less time to fill the borehole, avoids many accidents consequent on misfiring, and does not require so much tamping; in fact there is usually no need to tamp much if fine dry sand is used. Skilled tamping greatly increases the efficiency of the explosive.

Various other methods of charging are used when gunpowder is employed, but they are by no means free from danger.

When a high explosive or safety explosive is used, it is supplied in the form of a cartridge which is placed at the bottom of the borehole; a detonator is then attached and the hole filled with clay or sand as before. Dynamite charges are placed in the same manner as powder, the first stick being pressed into the bottom of the hole, then a primer or blasting-cap, with the fuse attached, is placed as near the centre as possible. The remainder of the charge is added and finally tamped with clay, sand, or brick-dust. Many quarrymen consider that placing the primer on the top or at the bottom of the charge gives just as good results as placing it in the middle. When firing electrically, care should be taken to connect the lead wires properly to the fuse, but never to connect the lead wires to the battery until everything is ready to fire. To prepare the primer when firing a safety fuse, the end of the fuse should be cut squarely across and placed in the cap, after first making sure that the fuse is perfectly dry. It is necessary, when pushing the fuse into the cap, to be careful that no twisting occurs. The fuse should just touch the fulminate or the varnish protecting it. Then with a pair of pliers or crimpers (and not with the teeth) the cap may be fastened on to the fuse. An opening is made in the dynamite stick with a wooden plug and the fuse is placed in this opening. The cap should touch the dynamite on all sides, since any space around it causes a cushion of air and lessens the effect of the detonation. The fuse is then firmly tied in place. The primer may be waterproofed by means of soap, tallow, or wax. The string holding the fuse in place should be of sufficient length to enable the primer to be lowered gently to the bottom of the hole. The charge should never be lowered by means of the fuse.

Cartridges containing dynamite should be quite pliable. If hard, they may have been frozen and will require to be thawed before use. This should be done by placing them for several hours in water at a temperature not exceeding 125° F.; boiling water should not be used, nor should the dynamite be placed near a fire.

The storage of explosives must be in accordance with the Explosives Act of 1875, and subsequent orders issued under that

Act. Particulars can be obtained from the Chief Inspector of Explosives, Home Office, London, S.W.

The *fuses* used are of two kinds—those ignited by a flame and those ignited electrically. Flame ignition is much more risky and uncertain than the use of electricity, so that the latter should be employed whenever possible.

Ignition fuses are of different kinds. One of the best—invented by Wm. Bickford in 1831—consists of a tube of jute filled with gunpowder and provided with an outer casing of rubber where necessary. The so-called " instantaneous fuses " consist of a series of wicks of compressed powder, the ends of which are fitted into a metal tube and connected to the slow fuse. These fuses are specially used for firing a number of shots simultaneously.

Electrical fuses are of two kinds, with high and low tension respectively. In the high-tension fuse the detonating mixture is ignited by a series of electric sparks which pass between two copper wires in the fuse, whilst the low-tension fuses contain a thin platinum wire which glows on the passage of the current and so ignites the priming. For sandstone and allied materials, a low-tension fuse is generally best and is much more certain in action ; moreover, it can easily be tested, which is not the case with a high-tension fuse.

The following are the chief reasons for preferring electrical exploders : (1) with an electrical exploder one hundred and fifty charges, or any smaller number, can be fired simultaneously ; (2) an electrical exploder allows the boreholes to be tamped better and gives the fullest confinement to the gases ; (3) there is a greater development of the explosive force and consequently a greater effect ; (4) an electrical exploder produces less smoke and fumes and permits the workmen to return more quickly to the working face ; (5) better results are obtained with a smaller quantity of explosive, so that an electrical exploder costs less to use ; (6) with a rheostat and galvanometer, the electrical connections can be tested to assure their being in order, and to avoid misfires ; (7) the shot firer stands at a safe distance and does not operate the exploder until every one is out of the danger zone : he has complete control of the entire blasting ; (8) there is no need for matches, torches, or open flames for detonating explosives, where an electrical exploder is used.

A *blasting-cap* or detonator, containing mercury fulminate or other suitable material, must be fastened to the end of the fuse which enters the borehole. The purpose of this cap is to transmit the spark from the fuse to the explosive in such a way as to start the explosion. When an electrical detonator is used no fuse is needed, the detonator acting directly on the cap. The cap should be carefully crimped on to the end of the fuse, so as to ensure the requisite contact. Blasting-caps are dangerous and should be stored in a dry place where they can do no harm ; they are spoiled by dampness.

tors should comply with the following conditions: nould contain a sufficient charge equivalent to at least ,, and preferably 1·75 grams, of pure fulminate (nitroes being taken as equal to double their own weight of e); (2) the fulminate charge should be disposed in such a way as to detonate with the highest possible velocity: this should be about 11,000 ft. per second for fulminate and 15,000 ft. per second for mixed detonators; (3) the length of the charge of fulminate should not be too great in proportion to its diameter, otherwise defective propagation may ensue.

There are four methods by which the power of a detonator may be tested: (*a*) the lead-block test, (*b*) impact test on sheet lead, (*c*) rate of detonation, and (*d*) practical tests on limit-density and humidity. Of these tests the second alone seems capable of being performed without the special facilities provided in a laboratory, but it has the disadvantage of not showing whether the detonation has been complete; method (*d*) appears the most reliable, though only comparative.

Since all cartridges are of approximately the same diameter, the detonator which will most easily produce complete detonation is the most powerful.

The exploder (sometimes called a detonator, though this term is usually applied to the primer) is a device for producing an electric current which, in turn, may produce a spark or heat a wire to redness according to the kind of fuse used. Of the various devices available for producing an electric current, a primary battery is uncertain, a magneto-machine requires periodical attention to keep the magneto in order, an accumulator is good, but requires frequent charging, and a dynamo machine is quite permanent and satisfactory in every way.

The capacity of an exploder is defined by the maximum number of detonators it can fire simultaneously, without any misses, at the end of a line having a given resistance. This capacity depends essentially on the nature of the detonator used and may vary within wide limits. It also depends on the velocity imparted to the mechanism by the shot-firer, but this cause of variation can be abolished by employing a spring that cannot be released until fully wound up.

The capacities stamped on the exploders are only approximate, and their real value should be tested from time to time by connecting up a certain number of detonators in series at the end of a line of known resistance, and finding how many can be fired at the same time without any failure. If the exploder is of the variable velocity type, the operating member should be actuated at a moderate speed to allow for the personal equation of the shot-firer. In order to establish a margin of safety, the resistance of the test-line should be greater than that of those actually used in practice (to allow for defective connections, etc.), and the number of the shots fired in a volley should, in prac-

tice, be about 25 per cent smaller than those successfully tried in the test.

The cable connecting the exploder to the charge should contain two separate copper wires well taped, insulated, and covered with plaited cotton. The cable should be kept on a roll or drum, and special care should be taken to avoid the formation of kinks. The electrical conducting power of the cable should be tested occasionally and any bare places covered with insulating tape.

Secondary blasting is a term applied to the use of explosives to large blocks which have previously been loosened from their beds but require to be still further reduced; such blocks are either drilled and blasted again as described on p. 297, using a smaller charge, or they are "mud-capped."

Mud-capping consists essentially in laying a high explosive on the block, covering it with clay and then exploding it. This method can only be used with explosives having an effect which is greater in a downward direction than in others. The charge should be placed on the spot which would be struck with a sledge-hammer if the rock were small enough to be broken in that way, and should be placed in a solid mass by slitting two or more paper cartridges and uniting the contents, taking care not to spread them more than necessary. A blasting cap crimped into the fuse should then be placed in the middle of the charge and the whole covered with 6 in. of damp clay or sand, pressed firmly over the explosive, care being taken not to cover the outer end of the fuse. If the block is cracked or seamy, the charge should be placed in a depression and covered with a quantity of clay or sand as described. Mud-capping is very wasteful of explosives, as 1 oz. of explosives in a 1-in. hole 12 in. deep has practically the same effect as 1 lb. of unconfined explosive laid under a mud-cap on the rock. On the other hand, drilling may cost as much as, or even more than, the additional explosive used in mud-capping.

Mining Sand-rocks

Mining is only employed for excavating sandstone, ganister, etc., when they occur under so great a depth of overlying strata that open quarrying is impracticable. The methods used are precisely the same as in other branches of mining, and are fully described in mining text-books.

Intermediate between mining by vertical shafts and open quarries is the use of a system of *adits*, drifts, or tunnels, extending in a sloping direction, usually of the same inclination as the dip of the material. Such an arrangement saves the cost of a vertical shaft and yet has all the other advantages of mining.

Adits are specially used in localities where the thin workable beds with a steep dip are worked from the outcrop. Where possible, the adit should be inclined downwards towards its entrance, as this facilitates drainage; it is not always possible to do this, as

the adit must, to a considerable extent, follow the dip of the beds.

The most common method of opening a mine or an outcrop is by horizontal entry. What is termed the "glory hole" method is employed in some mountainous regions. A tunnel is driven horizontally into a seam, and at the inner end of the tunnel a large chamber is blasted and used for the rock from above to be removed. A funnel-shaped shaft is then driven to the surface and the rock quarried round the opening in a circle of ever-increasing size, and the rock is gradually worked down into the chamber. Accidents are common, so that this method, whilst common, and often the cheapest, is seldom really satisfactory.

When working in an adit it is generally necessary to loosen the material by means of crowbars and wedges, explosives not usually being permissible. The loosened material is then hauled through the tunnel or adit to the open air.

Mining is so much more costly than open quarrying that the latter should always be used when possible.

The cost of quarrying may vary from 3d. per ton for a very soft material excavated and loaded with a steam navvy, to 3s. 6d. per ton for a hard rock. The cost of mining, on the contrary, is seldom less than 2s. per ton, and sometimes rises to 18s. per ton of material delivered into the pit wagons and drawn to the surface.

Loading Sand or Stone

By whatever method the sand or stone may have been worked, it must be placed in or on suitable wagons for transportation; this process is known as **filling or loading**. The method of filling depends largely on the nature of the material and the space available.

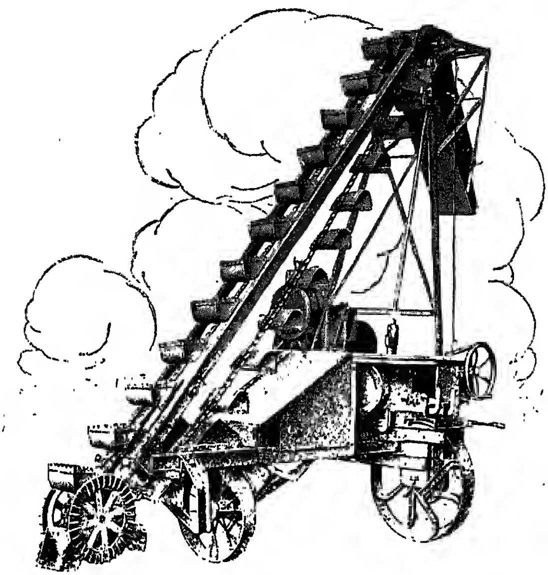
In **mines** where space is limited, hand-loading is usually employed, but in quarries where sufficient space is available, it is possible to employ more rapid means for loading the trucks for conveying the material from place to place. The principal means which may be employed are grabs (p. 287), steam navvies (p. 283), ladder excavators (p. 290), scoops (p. 282), and bucket elevators or "portable loaders" (p. 309).

Bucket Loaders.—Where the material is in sufficiently small pieces (*e.g.* less than 3 in. diameter) and it is to be loaded into large trucks, it is often convenient to use a bucket loader or similar device, consisting of an endless belt on a portable framework, the belt being provided with buckets (Fig. 41) and driven by an electric or petrol motor. If the inclination is not very steep, the buckets may be omitted and an endless belt used.

These loaders are so arranged that they can work at any suitable angle, and a spout, which can be moved radially, is fitted to the delivery end of the machine. Most of the earlier patterns of loaders required to have the materials shovelled into the buckets by hand, but the more modern ones are self-feeding. This great improvement

is effected in two ways: (1) the machine is forced into the pile of material during the loading process, or (2) a pair of rotary discs scoop the material automatically into the buckets.

A well-designed loader in good working order will deliver 1 cu. yd. of sand per minute as a fair working average, and will travel at the rate of about 60 ft. per minute in moving from one pile to another under its own power. When desired, two or more of these loaders can work in series or with belt conveyors. Such an arrangement is particularly convenient where it is necessary to



Winget Ltd., London.

FIG. 41.—Winget bucket loader.

convey the sand or stone over a pile of overburden or other material which it is not desired to move.

TRANSPORT AND HAULAGE

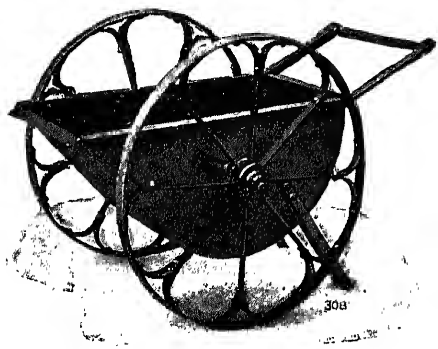
Various methods are used for conveying the sand or stone from the pit, quarry, or mine to the crushers, screens, etc.; several methods are often used simultaneously.

The use of **wheelbarrows** [1] and **horses and carts** is so familiar as to need no description. They are convenient, and for short

[1] For distances up to 30 yards a man with a wheelbarrow is usually cheaper than a conveyor for medium or irregular outputs.

distances are often economical, but in many instances could be profitably replaced by power-driven appliances.

All barrows should be built so that they are well balanced, the weight being thrown on the wheel and not on the man's hands; otherwise they will be difficult to drive and the output will be diminished Barrows are preferably lined with sheet steel so as to increase their durability. The top edges should be similarly protected, as these come in for considerable wear. Barrows with steel bodies and wooden frames are very light and strong, though more expensive than those made wholly of wood.



Ransome Machinery Co., Ltd., London.

FIG. 42.—Ransome tip-cart.

In connection with wheelbarrows, a useful device known as the Ransome Tip-cart (Fig. 42) may be mentioned. This consists of a peculiarly shaped body holding 6 cu. ft. of material, or three ordinary wheelbarrowfuls; it is made of welded steel plate, the body being mounted on a pair of steel wheels 3 ft. 6 in. in diameter. Owing to its peculiar shape and construction, one of these carts when full can be pushed by a boy without undue fatigue.

The amount which can be hauled by a horse is greatly increased if the cart is replaced by one or more wagons running on rails.

Tramways (Fig. 43), with either horses or mechanical haulage, are very efficient if well designed for the particular works in which they are used; but many tramways are quite inefficient on account of their being badly designed, or the rails not being taken sufficiently close to the face; this is a defect in the planning of the works rather than of the tramway as a method of transport.

Tramways are, in many respects, one of the most suitable means of transport, as they can be used in bad weather and under conditions where other appliances will fail to work. The original cost of construction is not excessive, and maintenance is small if the road is well cared for. If allowed to get into a bad state, tramways may cause great losses through the excessive wear and tear on the wagons, as well as through waste of power if the wagons are moved by rope-haulage. If the wagons are to be moved by men, it is not well for them to hold more than $\frac{3}{4}$ cu. yd. of material, and, for most purposes, rather less than this is preferable, whilst for pony-traction on a fairly level track about twice this capacity will be found convenient. If the wagons are unnecessarily small, time will be wasted, but if they are too large, additional men will be required

to assist; the latter are not fully employed in productive work and thus cause waste of money.

The rails of a tramway may be laid either temporarily or permanently, according to circumstances, or a combination of both temporary and permanent rails may be used. For very short distances men may push the wagons, but where the distance is more than 30 yds. the use of either horses or some form of mechanical haulage is preferable.

Mechanical haulage along rails is of three types: (*a*) single-rope haulage, (*b*) main and tail haulage, and (*c*) endless-rope or chain haulage.

The use of a rope or chain for mechanical haulage is to a large extent a matter of choice; in some cases a combination of the two is used—part of the track being controlled by a chain, with rope

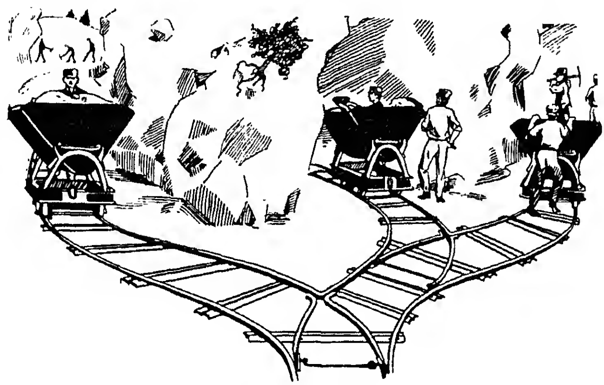


FIG. 43.—Tramway.

terminals for the better winding off the drum. Rope is usually preferred on account of its cheapness, but for steep inclines a chain provides a better gripping power. Freshly discarded colliery ropes are usually satisfactory for haulage in sand-pits, but require frequent inspection if accidents are to be avoided.

The **single-rope haulage** consists, as its name suggests, of a single rope, one end of which is attached to a wagon, whilst the other is wound round the drum of a crab or winding device, so that the wagon is drawn along by the rope. In a similar arrangement a chain is used, instead of a rope. The rope or chain, which varies from $\frac{3}{8}$ to $1\frac{1}{4}$ in. in diameter, may be *single* and wound on and off the drum, according as the wagon is being drawn up to or being lowered away from the machine. For this arrangement the track (which is single) must slope sufficiently for the wagons to travel down it of their own accord. A single rope of this kind is only suitable for small outputs or for large wagons. It has the disadvantage of making the engine run much more irregularly than

when "endless haulage" is used. A modification of the single-rope haulage consists of a double inclined track along which the loaded and empty wagons travel simultaneously in opposite directions. This arrangement is particularly useful in gravity haulage— loaded cars going down the incline draw up the empty cars without any power being needed (see p. 314). It is not always necessary to have a double track all the way, as if the ascending and descending cars or trucks always pass at the same point, it will suffice if the track is double for a short distance.

In **main and tail haulage,** one end of the rope or chain is wound off one drum, whilst the other end is wound on to another drum beside it. This is the ordinary form of haulage for collieries and other works where the endless system is inconvenient. Either a single or a double track may be used. The drums used for ordinary

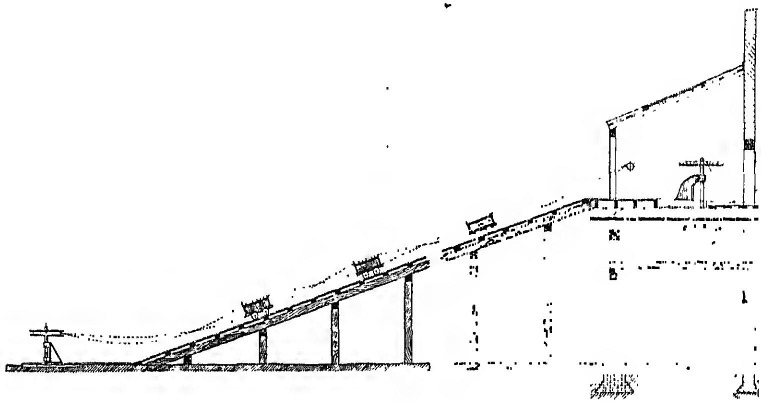


FIG. 44.—Endless haulage.

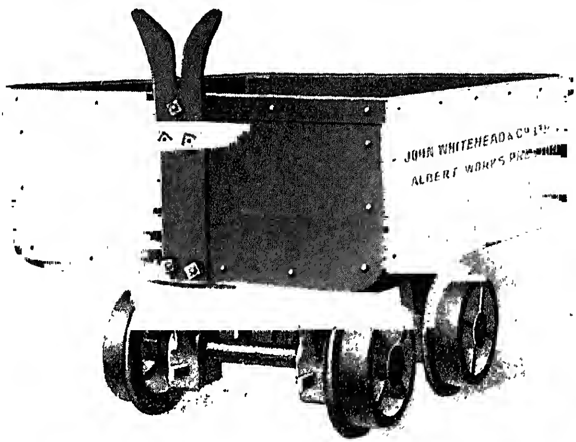
purposes are about 3 ft. in diameter, 4 ft. 6 in. long, revolving at about 150 revolutions per minute. They may be driven by steam, gas, oil, or electricity. The cable used is generally about $\frac{5}{8}$-in. diameter, the drum carrying 800 ft. of it. The direction of movement is reversed by means of a lever and gearing, the motive power working continually.

The cars or trucks usually carry about $1\frac{1}{2}$ cu. yds. of material and may be drawn up a gradient of 15 degrees at 350 ft. per min., a power of about 10 h.p. being then required for each car.

This method of haulage is suitable for relatively long distances over variable gradients, but under other circumstances it is wasteful in power, as there is no counterbalancing of ascending and descending loads, and the amount of rope required is very great ; consequently it is not used largely in open quarries.

In **endless haulage** (Fig. 44) the ends of the rope or chain are joined so as to make a continuous band, and the power is supplied by means of a horizontal pulley at one end. The wagons are

attached to this endless band at approximately regular intervals, so that the load on the engine remains fairly constant. This and the automatic nature of the haulage constitute the chief advantages of the endless system. A complete double track is desirable, but not essential; sufficient of it must be double to allow the return wagons to pass the loaded ones. It is also wise to have some form of ratchct and clutch on the shaft of the driving pulley, so that in cvent of a temporary stoppage of the engine the loaded cars will not travel backwards. The rope or chain is kept tight by a special tightening device, for which one of the terminal pulleys can be made to servc. To secure the necessary grip, the rope is coiled several times round the winding drum. The same purpose may be served



J. Whitehead & Co., Ltd., Preston.

FIG 45.—Y-shaped fork for rope haulage.

by passing it round two grooved pulleys, so placed that the rope warps itself partly round each. When a chain is used, a series of grips are usually cast on the driving wheel.

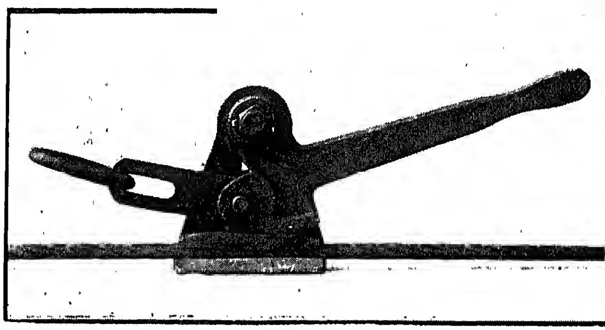
The wagons used for endless-chain haulage should have a Y-shaped fork which engages the chain (Fig. 45) and forms the simplest and easiest method of connection. Where this device is used, and the endless chain is made to rise slightly at the delivery end of the track, the wagon is automatically released as soon as it reaches the place where it is desired to stop it. This is done by taking the wagon to a rather greater height than is required and letting it run down a small incline at the last, the chain being raised well out of the way. Where a rope is used, a clip (Fig. 46) must be employed; this may also be released automatically.

One of the best non-automatic clips on the market at the present time consists of a clip which surrounds the rope and which

is opened and closed by a quick-acting screw. If the incline is not too steep, a simple Y-clip engaging the links of the chain is ample and satisfactory. Catches to prevent runaway cars from doing any damage are almost essential, though too seldom used.

The amount of material to be dealt with in an endless haulage system may be found by multiplying the number of wagons added per minute by the average weight of material in each wagon. It is usual for the rope or chain to travel $1\frac{3}{4}$-$2\frac{1}{2}$ miles per hour. The amount of power required varies from 5 to 40 h.p. according to the load, the incline; and the length of the track.

Which of these three systems is best under given conditions will depend on the number of wagons to be attached to the rope at once, and whether a double track is possible. Where two tracks are possible the endless type is generally preferred, when the individual



Longbotham Clip Co., Ltd., Doncaster.

FIG. 46.—Rope clip.

loads are not excessive. The direct winding rope with main and tail haulage is best suited for drawing the wagons over very uneven ground, as the engineman is then able, by watching the tightness of the hauling rope, to regulate his power to suit the changing levels of the track ; an endless rope, being run at one continuous speed, is not quite so suitable in such a case. Where the track is in the form of a fairly steep incline the use of a counterpoise will often effect a saving in the power required. This method is chiefly used for vertical lifts only, but it is equally efficient for steep slopes.

The rope or chain may be over or under the wagons, according to the circumstances. Suitable rollers must be provided for the rope to run on, and these must be well lubricated, or they will rapidly wear out the rope. For turning a curve, vertical rollers with a large flange at the bottom, to prevent the rope falling off, are used.

Gravity haulage is that in which the movement of the wagons is effected by gravity instead of mechanically applied power. Thus,

the loaded wagons running down an incline may be made to draw up a corresponding number of empty wagons merely by connecting both sets to a rope running round a pulley at the top of the incline.

The applications of gravity haulage are often very ingenious. Thus, by using one or more counterpoise wagons filled with water, a series of wagons loaded with stone, etc., may be raised to the top of an incline. The water may then be allowed to run out of the wagons at the bottom of the incline, whilst those at the top of the incline are filled with water. This arrangement is only practicable when the filling of the wagons with water is cheaper than the moving of the load by engine power. Occasionally, the water tanks rise and fall vertically and transmit their motion in a more horizontal direction.

In some cases where the force of gravity is not sufficient, a saving in engine-power may be effected by making use of counterpoise wagons and other devices, as far as these can be made available. Thus, in hauling material up a double inclined track, the empty wagons will act as a partial counterpoise to the loaded ones, and will reduce the driving power accordingly. To obtain the best results, the number of these empty trucks should be at least equal to that of the filled ones, and if material of any kind, such as rubbish, can be carried in the opposite direction to the load, an amount equal to half the useful load may be so carried, with great advantage, provided it does not interfere, in any way, with the working of the rest of the plant.

A powerful brake is essential in gravity haulage, as, if the loaded cars are allowed to travel too rapidly at first, they may break the rope and cause a serious accident. A simple, yet strong, form of band brake around the winding pulley is generally used. The provision of some safety device, either in the form of catch-points or otherwise, to prevent runaway cars from doing damage, is very desirable.

Wherever possible, it is desirable to make much use of gravity, as it is usually cheaper to lift the material to a single high point by applied power, if, from thence, it can be distributed by gravity to the points where it is required, rather than to haul it to these various points by directly applied power. There is indeed a considerable saving to be effected by making much more use of gravity than is commonly done.

Chutes of various kinds are invaluable when they can be arranged. If properly designed and constructed, they convey materials very rapidly and require no power or attendance. Much use might advantageously be made of them.

Ropes.—The ropes for haulage in quarries and mines are usually of wire and are $\frac{3}{8}$-in.-$1\frac{1}{4}$-in. diameter, but thicker ropes are used for heavy hauls. Table LXIII., by Messrs. Bullivant, shows the breaking strains of various kinds of wire rope.

TABLE LXIII.—BREAKING STRAIN OF ROPES

Circumference.	Diameter.	"Crucible" Steel.	Best Selected Improved "Crucible" Steel.	Best Selected "Mild Plough Steel."	Best Selected "Extra Plough Steel."	Approximate Weight per Fathom.
in.	in.	B.S. tons.	B.S. tons.	B.S. tons.	B.S. tons.	lb.
$1\frac{1}{4}$	$\frac{13}{32}$	$4\frac{1}{2}$	$4\frac{3}{4}$	$5\frac{1}{4}$	$5\frac{3}{4}$	$1\frac{3}{4}$
$1\frac{1}{2}$	$\frac{1}{2}$	6	$6\frac{1}{2}$	$7\frac{1}{4}$	$7\frac{3}{4}$	$2\frac{1}{2}$
$1\frac{3}{4}$	$\frac{9}{16}$	$8\frac{1}{4}$	$8\frac{3}{4}$	$9\frac{1}{2}$	$10\frac{1}{2}$	$3\frac{1}{4}$
2	$\frac{5}{8}$	11	$11\frac{3}{4}$	$12\frac{3}{4}$	$14\frac{1}{4}$	4
$2\frac{1}{4}$	$\frac{11}{16}$	$14\frac{1}{4}$	15	$16\frac{1}{2}$	18	$5\frac{1}{4}$
$2\frac{1}{2}$	$\frac{13}{16}$	$17\frac{1}{2}$	$18\frac{1}{4}$	20	$22\frac{1}{2}$	$6\frac{1}{4}$
$2\frac{3}{4}$	$\frac{7}{8}$	$21\frac{1}{4}$	$22\frac{1}{2}$	$24\frac{3}{4}$	$27\frac{1}{4}$	$7\frac{1}{2}$
3	$\frac{15}{16}$	$24\frac{3}{4}$	$26\frac{1}{2}$	29	$31\frac{3}{4}$	9
$3\frac{1}{4}$	1	$29\frac{3}{4}$	$31\frac{3}{4}$	35	38	$10\frac{1}{2}$
$3\frac{1}{2}$	$1\frac{1}{16}$	$34\frac{1}{2}$	$36\frac{3}{4}$	$40\frac{1}{4}$	$44\frac{1}{4}$	13
$3\frac{3}{4}$	$1\frac{3}{16}$	$39\frac{1}{2}$	42	46	$50\frac{3}{4}$	$14\frac{1}{2}$
4	$1\frac{1}{4}$	$45\frac{1}{2}$	$48\frac{1}{2}$	53	58	$16\frac{1}{2}$
$4\frac{1}{4}$	$1\frac{3}{8}$	$52\frac{1}{2}$	56	$61\frac{1}{2}$	67	$17\frac{3}{4}$
$4\frac{1}{2}$	$1\frac{7}{16}$	$57\frac{1}{2}$	61	67	73	20
$4\frac{3}{4}$	$1\frac{1}{2}$	65	69	76	83	22
5	$1\frac{5}{8}$	72	76	83	92	25

Wire ropes require frequent attention, as they are subject to heavy wear and tear, and unless examined and repaired sufficiently often, they may fail and cause a serious accident. Bending the rope round too small a sheave, pulley, or drum, will also cause strains which may easily damage it. The effects of abrasion and cutting action are also serious, but may be kept within reasonable limits by efficiently lubricating the rope with a hot mixture of tar, linseed oil, and tallow.

Ropes for hauling should never be overloaded, nor should they be applied to the load, or the load to them, with a jerk, as this has an equally detrimental effect. Similarly, the rope should not be allowed to strike any posts, or other fixed objects, which cause unnecessary rubbing, as these wear it away and soon reduce its strength to below that which is safe.

Points and Turn-tables.—Special care is needed in the selection of points, particularly movable ones. In planning a works, care must be taken to avoid inserting too many points, as these affect the smoothness of the running. It is also necessary for the wagons to run more slowly over the points, in order to prevent them from being derailed. Points are, however, to be preferred to turn-tables, and the latter should only be used when really necessary. It will often be preferable to take the wagons several yards farther and use points, than to have a shorter distance and use a turn-table. When turn-tables are used they should be kept in first-class condition, so as to turn easily, to be dirt-proof, and need little attention. By using a ball-race for the turn-table, most of the friction can be avoided. It is most important that the dirt should not gain access

to the race, but if it should do so, the tables ought to be desig that it may be removed in a minute or so.

Turn-tables are usually permanent structures, but for some purposes a climbing turn-table is better. A climbing turn-table consists of a large iron plate of special shape, which can be laid over the rails and is provided with sloping sides, so that the wagons travelling over the track run on the turn-table, and may then be turned in any desired direction and guided to another set of rails. Such a turn-table can be placed at any portion of the track to form a temporary switch in places where permanent points are undesirable. It is most commonly used to take wagons in a direction at right angles to the main track when forming a heap for weathering, or filling and emptying trucks. It has several other uses, and its application in many works might usefully be extended.

Rails.—The track of a works tramway should be skilfully selected, and it is essential that it should be well laid on soundly bedded sleepers to which the rails are securely fastened, preferably by means of bolts, which are cheaper in the long run than the more usual nails. The dimensions of the rails must be selected according to local requirements. For the lightest portable rails a weight of 8 lb. per yd. is usually satisfactory, but for permanent tracks it is better to use rails weighing about 22 lb. per yd.

When curves have to be traversed, the " outer " rails should be raised above the level of the inner ones. The amount of elevation can be calculated from a suitable formula, but it is usually best to raise the rail much more than the calculated amount. At the low rates of travel in sandstone workings, the amount of elevation need seldom exceed 5 in.

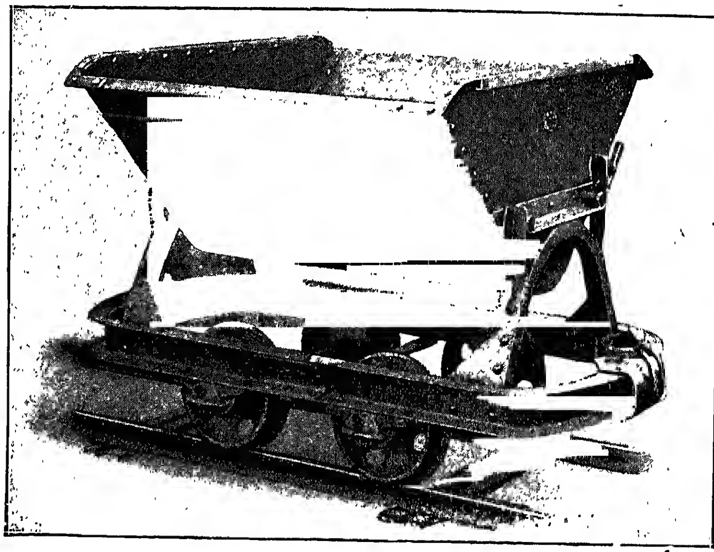
It is highly advisable to place the maintenance of the rails and turn-tables in the charge of one man, who should be compelled to keep all the tools, nails, bolts, etc., he requires, in a special box, which he should take with him to the place where repairs are needed. If this is done, great care being taken that the tools, etc., are not, on any pretext whatever, allowed to lie about and that the disused bolts are carried away to their proper place, many annoying incidents which result from losing tools, and much of the time lost in fetching them, will be saved. These may appear small matters, but they are none the less important.

The *sleepers* should be arranged across the track as in a railway, and not parallel to the rails, as the latter arrangement, though much cheaper, is not nearly so satisfactory. The sleepers may be of wood, steel, or concrete ; it is very difficult to say which is the best material when price has to be considered, but most quarry managers prefer them in the order mentioned.

Wagons, Tubs, or **Cars,** which run on rails, have a capacity of 5 cwt.-1½ tons when used inside the works area, the ordinary railway trucks being employed for longer distances. Horse-drawn carts should only be employed where other vehicles are less convenient. Motor lorries are being increasingly used for transport by

road, for distances up to 40 miles; beyond this they are usually not so cheap as railway transport, though much depends on local circumstances.

The tramway wagons or "tubs" usually employed for single-rope haulage have a capacity of about $\frac{3}{4}$-1 ton of material. A particularly convenient form is that known as the "Jubilee" pattern (Fig. 47), supplied by several firms. These wagons may be made to tip sideways or endways.



F. Mann, Ltd., Cardiff.

FIG. 47.—Jubilee wagon.

The requirements of a good wagon, tub, bogey, corve, or whatever name these articles may be known by in different parts of the country, are: (1) strength, (2) lightness, (3) stability, (4) compactness, (5) easy running, and (6) easy discharge. Ball-bearings are increasingly used in the construction of wagons, and it is, in any case, desirable to oil or grease the bearings at very frequent intervals. Easy discharge is particularly important in the case of "tipping wagons." Some of the more recent designs are particularly convenient in this respect, and combine great natural stability with remarkable ease in emptying. At the same time, the body of such a wagon must be so fastened that it will not discharge its contents accidentally.

The wagons should be made of steel-plate with angle irons, stout rims, and a strong angle-steel frame. The wheels should be specially toughened and provided with ball-bearings for easier running. The body should be well balanced so as to tip easily

when required, but should be provided with a simple, reliable fastener to keep it from tipping unexpectedly. Where several cars are to be fastened together, swivelled couplings are desirable.

When endless haulage up a steep incline is necessary, small oblong wooden or steel wagons, each holding about 8 cu. ft., are very satisfactory. These are run into a tipping frame, and so are emptied quite as easily as when tipping wagons are used, whilst the cost of plain wagons and a tipping frame is much less than that of the tipping wagons. Unfortunately, tipping frames can only be used where the material has to fall to a lower level than the track, whereas side-tipping wagons of the type illustrated (Fig. 47) can tip on to the level of the track.

Small wagons distribute the load more uniformly on an endless rope or chain, and they feed the crushers or other machinery much more regularly than a smaller number of larger wagons, and so effect a saving in power as compared with large wagons. They are also easier for the men to handle at the quarry or in the mine.

In cases where the material might be stained by rust from steel or iron cars, wooden bodies mounted on steel frames may be used. Wooden cars should be built of well-seasoned oak, solidly braced and bolted, not nailed. They should be so constructed that any part can be removed without damaging the remainder. The iron or steel framework should be stout and the wheels heavy and sound. It is a great advantage if the cars are fitted with ball-bearings and self-oiling boxes.

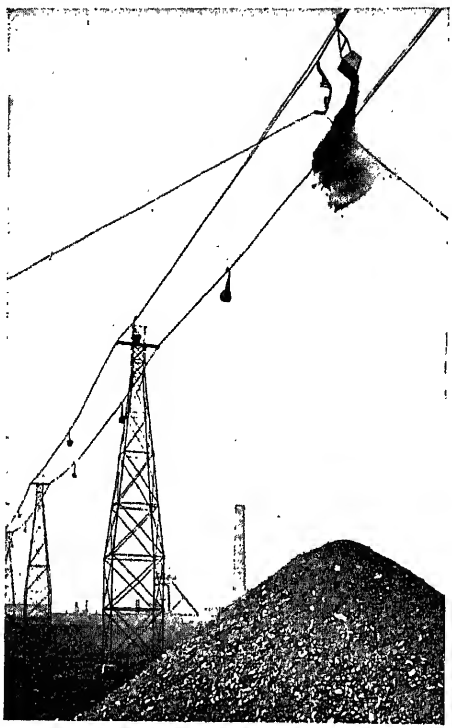
The *bearings* used in cars are of great importance, as upon them the ease or otherwise of the traction chiefly depends. There is a considerable difference of opinion as to which form of bearing is best, but there can be little doubt that ball- or roller-bearings, when well cased and properly looked after, afford the easiest running of cars, though they are more costly in the first place. Quarry managers who have sufficient foresight to recognise that easy-running cars do more work and require less traction, almost invariably use cars with ball- or roller-bearings. In each of these forms, the axle is surrounded by a ring of steel balls or rollers, working in an outer steel ring which forms the lining of the "box" of the bearing. There are various types of ball-bearings on the market, and the builders of cars will fit such bearings on to any car, if required to do so. The first cost of the car is of less importance than is commonly supposed, as cheapness usually means sacrifice of one or other desirable quality, chiefly low power to propel the car and rapid transport.

If the track crosses the public road, it is desirable to have some form of brake attached to the wagon, or, in the case of pony-drawn tubs, the pony should be fitted into fixed shafts and not in the usual loose chain traces. For tracks entirely on the works, a brake is not quite so necessary, though still desirable.

Where the wagons have to be used on an incline of 1 in 2, they are liable to fall over, and cannot be filled without some of the

material falling out on the journey. To overcome this difficulty, they may be mounted on another car of such a shape that the wagons remain level whilst the frame car passes up and down the incline. These special frame cars can only be used on a uniform gradient.

To prevent tipping cars from slipping whilst dumping their contents, it is often convenient to employ some form of simple catch. Unless this is done, the men engaged in unloading the cars may be injured, and, in any case, time is lost by the occasional derailing of the cars. Various forms of tie and catch are in use, but one of the best consists of a simple iron bar, the top of which is sufficiently high to clear the frame of the car without giving much play. Hence, when the car is being tipped, the frame cannot move forward, but is held by the top bar and all slipping is prevented. So simple an appliance can be made from odd bars for a few pence.



Ropeways, Ltd., London.

FIG. 48.—Aerial ropeway.

Ropeways or **Aerial Ways** (Fig. 48) are a modification of rope haulage, in which the rope, instead of pulling the wagon along, actually carries the "wagon," which is usually in the form of a box or large bucket. As a matter of safety, the bucket should be fastened to the rope whilst it is in motion. It may be released at the end of its journey, or it may remain permanently attached to the rope, the material being filled into buckets at one end of the track and emptied at the other by releasing a pin, which causes the bucket to tip over, or allows one side of the bucket to fall out. Where the nature of the ground does not permit the construction of an ordinary tramway (as where a deep valley intervenes between the source of supply and the destination of the material), an aerial

ropeway has the advantage of reasonable cost, small maintenance charges and high capacity. It also has the advantage that the space between the quarry and the destination of the material, instead of being occupied by a tramway, may be used for any other purpose for which it may be suitable. Unfortunately, the initial cost of overhead ropeways is so great (it is seldom less than £1500) that they can only be used for large outputs, or for abnormally long distances, and even then, unless at least five tons per hour is to be transmitted, they are not economical. A simple overhead ropeway may sometimes be made in a quite rough and homely fashion; this is economical for short distances and loads of 1 ton per hour. Care should be taken to make it of ample strength.

Overhead ropeways are of three types: (i.) those in which the buckets are fixed to a travelling rope and are carried by it from one end of the journey to the other, and back again; (ii.) those in which a fixed rope is used to carry the buckets, which are provided with pulleys and are hauled along the rope; and (iii.) an endless ropeway of either of the foregoing types.

The second and third types are most economical where the output is sufficiently large, the first type being used chiefly for small works.

The difference between a modern, properly constructed plant and the inferior class of ropeway may be seen, in the first place, in the structural work for the towers and stations. There is a choice of two alternatives, and in climates which are not exceptionally deteriorative to timber there is much to be said for its use for ropeway plants. In normal cases it costs 20-30 per cent less than steel construction, and whilst the latter is of course preferable, it is not absolutely necessary. The cost may usually be reduced if the intending purchaser obtains the prices of pine timber (cut both round and half-round) from local dealers and states these prices to the ropeway manufacturers, as it is generally immaterial to them from whom the timber is bought. If timber is chosen as the material for the structural work, it should be creosoted, or at least those parts of the timber posts which go into the ground should be thoroughly tarred. Every few weeks, for the first two years, it will be necessary to go over the bolts which bind the timber together, in order to tighten them, as the timber contracts considerably under outdoor influences. The necessary foundation work for these structures may be of either concrete or masonry work, and most manufacturers will choose the latter if bricks are readily obtainable, as brickwork is often cheaper and more reliable than concrete. In some cases, the timber towers can be erected without any foundation whatever, but for steel-work towers a foundation is essential.

The track or main carrying rope is of great importance, and only ropes made of the best quality of steel should be used.

The chief causes of rope breakage are the brittleness of the steel

and the faulty design of the plant. Brittleness is usually a result of an attempt to give the rope an extremely hard surface, which will resist the wear and tear of the carrier-wheels. Faulty design is most frequently shown in sharp beds and kinks in the rope, which strain the individual strands to such an extent that they easily break; a skilful designer is very careful to lay the cable so that no sharp bends are given to the rope, and this, if the rope s of ample strength and of a skilfully selected quality, ensures the greatest possible length of life.

The length of time the carrying ropes or cables will last depends chiefly on the quality and the construction of the rope; six years is a fair average, though many ropes have lasted double that time.

The most generally used form of rope is a *spiral rope* in which each individual wire or strand is round, and the whole of the wires composing the rope are spirally interwoven together in such a manner as to form a self-contained continuous rope. This type of rope is cheap and serves as a good track cable, but unfortunately its surface does not present a continuous whole or smooth surface to the carrier wheel, and consequently a great amount of friction has to be overcome, which naturally wears out the rope. Further, when one of the strands of the rope breaks, it immediately springs out from the surface owing to its natural elasticity, and a rope jacket must be placed on the rope, over the broken wire, to bind it down again. Unless this is done, the protruding wire will catch against the wheel of each carrier and may throw it from the track. Rope jackets of sheet steel only cost a few pence each, but sometimes the rope is high above the level of the ground, and is not readily accessible. To remedy these disadvantages, several types of locked and semi-locked ropes have been designed, with which it is practically impossible for any such interruptions to occur in the traffic; such ropes also have a smooth surface, which presents a much better track to the carrier wheels, creates less friction, and thus reduces the wear on the rope as compared with that on spiral ropes.

The cable should be supported on lengthy bearings or slideways, in order to avoid any sharp bends; it should be suitably anchored at one end station and tensioned in the other. Some makers attach a telescopic spring to either end of the ropes, whilst others use pulley blocks or screw gear for taking up the slack of the ropes. The best method is to use a large tension weight, hung so as to allow free sliding up and down, according to the variations in the rope, and to keep it always at a fixed tension; this method has considerable advantage over the others mentioned above.

The hauling rope should be carefully selected, in order to obtain as smooth a working of the plant as possible. A rope with a hemp core should be used. The end-sheaves around which this rope runs should be of large diameter, so that the individual strands of the rope may not be injured in bending around it. The grooves of the pulleys of the driving gear may be lined with leather or

wood so as to increase the gripping action on the rope. The rope should also be suitably supported by rollers on the towers, in order to obtain a proper clearance above ground level. In the station opposite to the driving terminal, the traction rope should always be tensioned in a manner similar to the carrying ropes, but a longer play for the weight must be allowed, as very considerable variations occur on the hauling rope. If these variations are not controlled automatically, the hauling rope becomes slack, and consequently the driving gear continues to revolve, whilst the traction rope remains stationary, with disastrous effects to the strands of the rope.

The driving gear must be carefully designed and should under no circumstances consist of a single drum, round which the traction rope is wound two or three times to give the necessary grip. This method, which is used by some makers, severely injures the traction rope and reduces its life to one-half of what it would be if properly designed driving gear were used. The drive from the main sheave to the motor or engine is best effected through bevel gearing, although ordinary straight-toothed or spur-gearing may be used if desired.

The carriers or buckets usually consist of a two-wheeled trolley, the wheels of which must be of good malleable iron or, preferably, of cast steel. Cast-iron wheels, after the hard, chilled outer surface has worn off, rapidly wear unevenly, with the result that when a worn part of the rim of the wheel comes into contact with the surface of the track cable, the wheel ceases to revolve and slides along the rope, instead of running along it. When this happens to several, or possibly all, the carriers on the line, the friction is so great that the driving power may not be strong enough to overcome it and the transport is consequently stopped, and in any case the wear on the rope is greatly increased.

The wheels of the carrier or trolley should be supported on axles fitted into steel side-plates, and from this carrier the hanger which holds the bucket, and to which the hauling rope grip is fastened, should be hung. The general appearance of such a carrier may be seen from Fig. 49.

The bucket should be made of sheet iron or preferably of sheet steel. When the buckets are to be automatically discharged, a tipping lever must be fitted and the pivots on which the bucket is supported must be placed below the centre of gravity, so that the bucket cannot retain its position unless it is held fast by the tipping lever; consequently, when a catch strikes the tipping lever and knocks it out of place, the bucket tips over and the whole of the contents is automatically discharged.

Fig. 50 shows an ordinary pit tub, hung from the carriers of a ropeway trolley. This arrangement enables existing rolling stock to be utilised for the ropeway transport, the tubs being carried by chain slings, which are slipped on the hooks of the tubs and the carrier dispatched from the ropeway terminal on to the

ropeway track, a process to which an ordinary labourer or youth can easily attend. In most cases it is preferable to use a carrier specially designed for a ropeway. The heavy wooden trucks used on inclined haulage systems are unsuitable for a ...y, as their great weight would necessitate very heavy carrying ...raction ropes, with a consequent increase in the initial cost ...nstallation of the ropeway; the power required would be unnecessarily great and the maintenance expenses would be unduly large, on account of the heavy wear and tear on the ropes occasioned by the heavy wagons. If the standard type of ropeway carrier is used, the loads will be more uniformly distributed along the

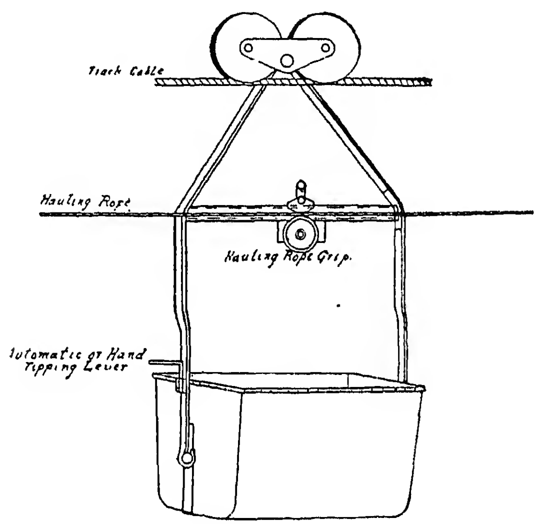


FIG. 49.—Carrier for aerial ropeway.

rope and the excessive strains due to the use of heavy wagons will be avoided.

The loading end of the ropeway should be as near the working face as possible, and it should be extended from time to time either by light-gauge tramway tracks, if tubs are used, as illustrated in Fig. 50, or by an overhead track, if standard buckets are used, as in Fig. 49. The overhead track usually consists of a rigid rail, suitably supported, or hung from iron trestles, as illustrated in Fig. 51. These trestles are quite simple to construct, and for loads up to half a ton can be made of light timber 5 in. × 5 in., with the cross beam 8 in. × 4 in., whilst for buckets above this weight and up to one ton, 7 in. × 7 in. timber, with an 8 in. × 6 in. cross beam will be ample. The rail of this overhead track must end exactly at the same level as the station rails, so that the ropeway cars,

when uncoupled from the traction rope, may run straight on to the track, and *vice versa*. The trestles and rails may be laid in any direction, and are taken up and relaid as circumstances demand. The rails can be made of ordinary flat or angle iron of a sufficient strength to bear the cars which will travel over them. Unfortunately, the cost of extending an overhead track is much greater than that of laying light rails, so that whilst the overhead track has several advantages, and is the only practicable system in some instances, a tramway system often proves to be cheaper.

The grip for attaching the car to the rope has been the subject of many patents, yet there are few good grips which can negotiate

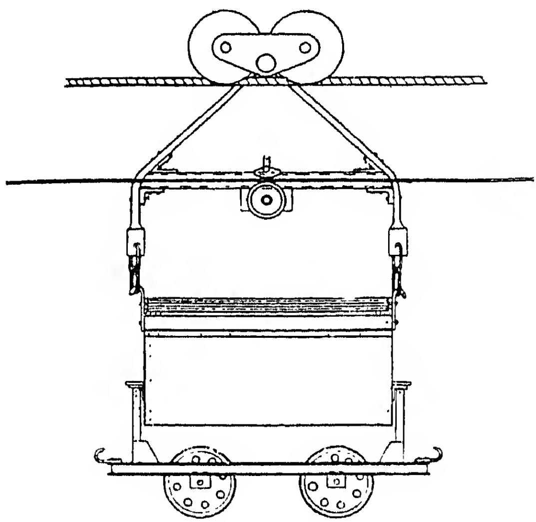


FIG. 50.—Pit tub on aerial ropeway.

gradients of 1 in 1. As a sharp rise from the quarry or pit often requires a gradient of this steepness, the purchaser should very carefully satisfy himself as to the efficiency of the particular grip he has under consideration. On the other hand, it is a wise precaution, wherever possible, to excavate part of the ground, or to alter the positions of one or more of the towers, so as to lessen the steepest parts of the gradient. Friction grips are usually the most convenient where the incline is not too steep, but for severe gradients screw-grips are safer, though much more troublesome. For any given works, that grip should be selected which, whilst affording the necessary safety after prolonged wear, is the easiest to use in attaching the carrier or removing it from the rope.

It is often convenient to use carriers which can be lowered to the quarry floor and raised almost to the level of the rope during

transport. Such a device (known as a *blondin*) consists of a framework which runs on a track rope, and is fitted with a pulley and rope operated from one end of the track, so as to lower or raise the bucket from the framework. Blondins are particularly suitable for raising loads of less than 5 tons out of deep quarries. They should be worked as rapidly as is consistent with safe working; in many works, they are driven too slowly—particularly on the

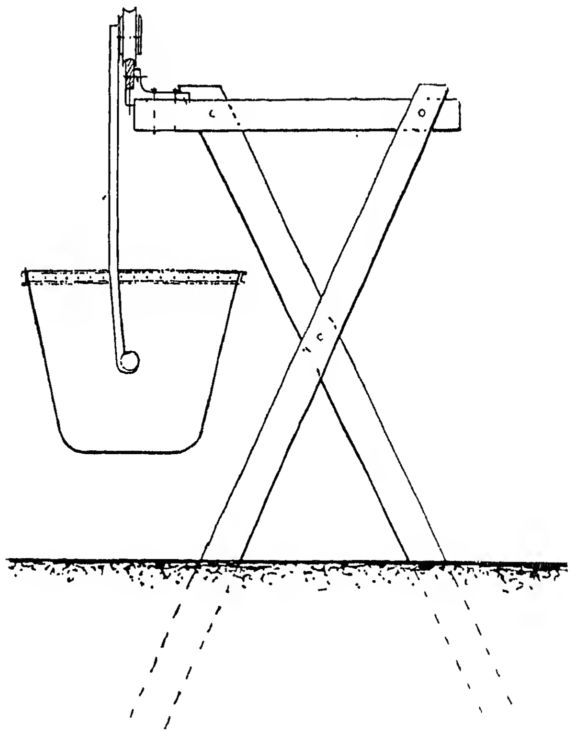


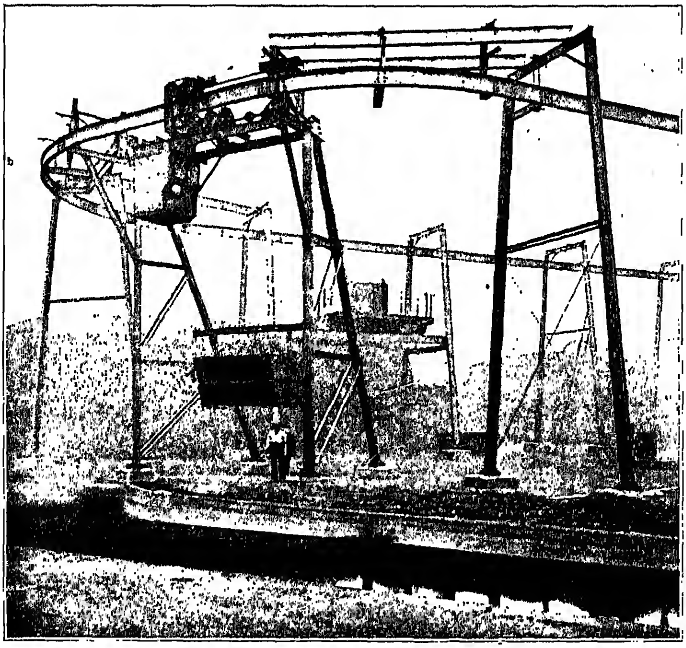
FIG. 51.—Ropeway extension on telpher-track.

return journey, with the result that the output is lower than their true capacity. When carrying a full load the bucket may travel at the rate of 250-300 ft. per min., but the empty bucket should not travel at less than 400 ft. per min., and may usually travel much faster.

An automatic weigher and totaliser, such as those manufactured by W. & T. Avery, of Birmingham, may be used to record the amount of material passing over the ropeway.

Where there is any risk of damage by material falling from the buckets, a stout network should be spread beneath the ropeway.

Mono-rails or **Telpher Lines** (Fig. 52) are rigid aerial ways, in which the buckets are carried on a steel rail. Strictly the term "telpher" should be confined to those devices in which the motor is attached to the moving bucket or carrier, but many other mono-rails are now known as telphers. True telphers are seldom used in quarries, as the simple and less expensive mono-rails and rope-ways are usually sufficient, but telphers are always worth consideration, when unusually large quantities of material have to be moved.



Strachan & Henshaw, Ltd., Bristol.

Fig. 52.—Telpher line.

Mono-rails are commonly limited to short distances of 150 yards or less, as for longer distances ropeways are cheaper, and on that account are preferred. Mono-rails are, however, very useful at one or both ends of a ropeway, as they facilitate loading and unloading (Fig. 51).

The rails usually consist of an ordinary I-girder, the bucket or carrier being suspended from an attachment such as that shown in Fig. 53, in which the wheels run in two half-grooves to ensure smooth running, especially around curves. The haulage appliances are similar to those of aerial ropeways, the chief difference between a ropeway and a mono-rail being in the greater rigidity of the latter.

Lifts in the sand industry are chiefly of the "cage" variety; they are occasionally used for conveying material from deep quarries, but chiefly for raising the sand to the highest part of the crushing and screening plant, so that its later movements may be effected solely by gravity. In the United States particularly, it is customary to erect very high crushing, washing, and screening plants, and cage-lifts of the ordinary vertical type have been found to be the most efficient means of elevating the sand to the required height. A simple form of lift, in which the cage is raised and lowered by means of a rope passing over a pulley at the top of the structure, is quite satisfactory, but it is important that it should be skilfully designed and provided with adequate safety appliances.

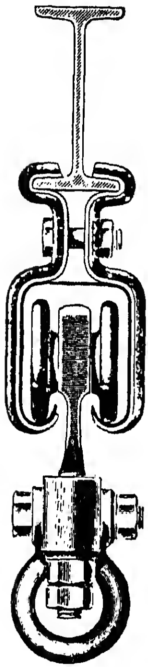


Fig. 53.—Telpher support.

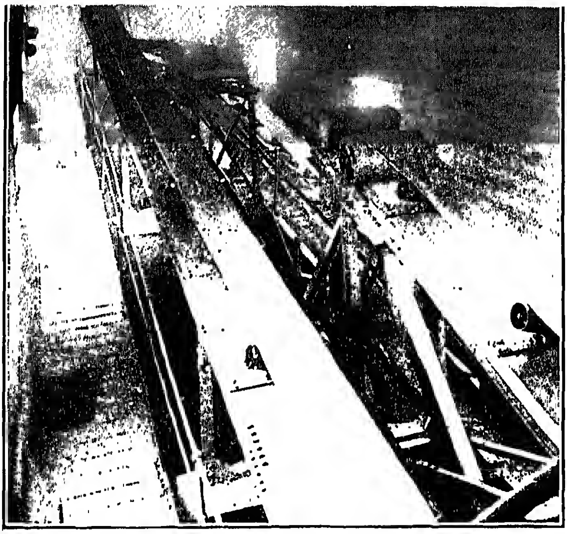
Conveyors.—Where the sand or stone cannot be tipped directly into the grinding machine or bins, conveyors are frequently the most economical means of transport. They are exceedingly useful when removing overburden, or working loose deposits with a steam navvy which discharges the material into a hopper above a conveyor; the latter either carries the useful material to the plant, or the rubbish or overburden to a part of the pit on which it may be deposited without causing any future inconvenience. Conveyors are also used for taking the sand from dredgers to the land, for distributing sand in piles or bins, for storage, and for withdrawing sand from heaps or bins for use.

Conveyors have an enormous capacity and an almost constant delivery—two important advantages in sand transport. They consume a moderate amount of power and are applicable in many ways, provided the distance is not too great. In no case should they be used for distances exceeding 1000 yards, and in most instances 500 yards may be regarded as the maximum. Conveyors require very little room and the cost of the upkeep is relatively small, whilst their efficiency and convenience are both high, so that they are well adapted for use in working sand.

Conveyors are of numerous types. Those chiefly used for the transportation of sand and stone are: (*a*) belt conveyors, (*b*) drag-plate and scraper conveyors, (*c*) bucket conveyors, and (*d*) jiggers or shaking conveyors.

Belt Conveyors (Fig. 54) are by far the most commonly used for carrying sand in an almost horizontal direction, though if baffles are placed on the belt they may be used for inclines up to 1 in 1. The maximum length of a belt conveyor is determined by the fibre stress in the belt and is, therefore, closely related to the load and speed. Conveyors which are horizontal may naturally be longer

than those required to elevate the material. Conveyors 1000 ft. from centre to centre, amply supported by runners and carrying 500 tons per hour, are in satisfactory use. A conveyor belt should usually be made of strong, woven hemp or specially prepared canvas (rubber alone stretches too much), and the edges should be bound with cord to prevent their wearing too rapidly. A coating of tar on the belt will increase its durability. Other materials may also be used, either as a protection to the surface of the belt, or for its complete construction. Thus, belts composed of bars of wood or metal united by steel links are sometimes



Mitchell Conveyor Co., Ltd., London.

FIG. 54.—Belt conveyor.

employed, and recently belts made of thin steel have been extensively used in a few works with highly satisfactory results.

Where coarse materials, such as stone, are to be conveyed, a chain- or link-belt is often preferable, especially as it may also be used as a coarse screen for separating the smaller particles; such a belt is particularly useful in separating and removing gravel from sand.

Belts of cotton, hemp, or prepared canvas, such as balata, are the most extensively used as conveyors. Such belts, which in general shape and appearance resemble those used for driving machinery, pass over two pulleys—one at either end—and over a number of guide rollers, or "idlers," arranged at intervals along its course. Where the quantity of sand to be carried is sufficiently large, the plain guide rolls may be replaced by sets of three rollers,

so arranged as to bend up the edges of the belt, and thus form a channel in place of the flat surface. When such a trough conveyor is used, the belt may, with advantage, have a flexible joint running lengthwise of the belt and a few inches from its edge, so as to make it easily conform to the shape required and to prevent any sand from spilling over the edges.

For large outputs, the use of a belt in the form of a trough is better than a flat belt, as the latter requires side boards extending along its entire length in order to prevent spilling, but trough belts are never very efficient, and the trough-forming pulleys are a prominent cause of wear on the belt. One pulley round which the belt passes rotates in fixed bearings and is driven from the engine or shafting; the other end-pulley should be fitted in a movable frame with sliding bearings, so that the tension of the belt may be kept constant and sagging avoided. All the bearings should be provided with caps to prevent dust or dirt falling into them. On the under side of the frame of a horizontal belt, idler pulleys should be fitted about 20 ft. apart, to support the returning portion of the belt.

The belt conveyor has one advantage over most other types of conveyors in that it may be driven from any point in its length, though an end-drive is preferable. If the belt conveyor is inclined it is generally desirable to place driving pulleys at the upper end, otherwise the slack part of the belt would be on the upper or working surface, which is very undesirable; driving from the lower end of an inclined belt also neeessitates increasing the tension on the belt, whieh is another unsatisfactory feature.

The use of an intermediate drive using "snub" pulleys, though satisfactory for soft materials, is undesirable for hard and angular materials such as sand, as the particles tend to become embedded in the belt and will, in time, injure it. Snub pulleys also have the disadvantage of forcing the working sides of the belt, when at greatest tension, against the face of the pulley. To secure economical working it is essential that the belt should travel at a fair speed, usually about 240 ft. per min., but an excessive rate must be avoided, especially with fine sand, or the material will be wasted in transit by being blown off the belt. Short belts less than 14 in. wide may usually travel more rapidly than long ones.

Ordinarily, a belt conveyor is loaded at one end, but if desired it may be fed at any other point prior to that of discharge. It is usual to discharge the material at the end remote from that at which the load is supplied, though it may be discharged at any point by placing a vertieal board at an angle across the belt, so that it diverts the material, whilst allowing the belt to travel forward. A series of such diverters may be used to enable one belt to supply material to each of several bins in turn, the diverters being moved as each bin is filled.

It is advisable to provide some mechanism to clean the belt after it passes over the discharge pulley, rotary brushes made of

various fibres being generally used. These brushes revolve rapidly, sweeping the material into the chutes. They are driven by an extension of the conveyor pulley, and are provided with means for adjusting the brushes for the wear of the fibre.

The various runners, pulleys, etc., are usually carried on a frame which may be of wood or steel—preferably the latter—one end being bolted to the head-gearing frame. The shafts and gearing should be proportionate to the width and length of the conveyor. Table LXIV. shows the size of the various rollers required for belts of different widths.

TABLE LXIV.—BELT CONVEYOR ROLLER SETS. (G. Mitchell.)

Width in Inches.	12.	15.	18.	21.	24.	27.	30.	36.	40.	44.	48.
Top Rollers:											
Diameter . .	5	5	6	6	6	7	7	7	8	8	9
Width . .	4	5	5½	6	7½	8¼	9	10½	10½	10½	10½
Tube spindles .	1	1	1¼	1¼	1½	1½	1½	1¾	1¾	1¾	2
Bottom Rollers:											
Diameter . .	4	4	5	5	5	6	6	7	7	8	8
Width . .	14	17	20	23	27	30	32	38	42	47	51
Solid spindle .	1	1	1	1¼	1¼	1¼	1½	1½	1¾	2	2
Top Edge Guides:											
Diameter . .	4	4	4	5	5	5	5	6	6	6	6
Width . .	3	3	4	4	4	5	5	5	5	6	6
Tube spindles .	1	1	1	1¼	1¼	1¼	1½	1½	1¾	1¾	1¾

The thickness or ply of the belts used need not trouble the purchaser to any great extent, as the maker will generally see that the ply of a belt is suitable to its width. Table LXV., however, shows the most generally satisfactory plies.

TABLE LXV.—BELTS FOR CONVEYORS. (G. Mitchell.)

Width.	Plies. Stepped. Centre.	Edges.	Ordinary. Equal Plies.
Not exceeding 12 in.	2	4	3
,, 18 ,, ...	3	5	4
,, 24 ,, ...	3	6	5
,, 30 ,, ...	4	6	5
,, 40 ,, ...	5	7	6
,, 48 ,, ...	6	8	7

Output of Belt Conveyors.—The output of a conveyor depends to a large extent on the manner in which it is used, as the "personal factor" plays a large part in controlling it. Table LXVI. shows the approximate capacity of belt conveyors of different widths.

BLE LXVI.—HORIZONTAL BELT CONVEYORS ON 100-FT. CENTRES.
(G. Mitchell.)

inches .	12.	15.	18.	21.	24.	27.	30.	36.	40.	44.	48.
iving and drum	18	20	22	24	27	30	33	36	38	40	42
ension . . .	15	18	20	22	24	26	28	30	32	34	36
Vidth of both above	14	17	20	23	27	30	32	38	42	47	51
earing ratio . .	3 : 1	3 : 1	4 : 1	4 : 1	4 : 1	5 : 1	5 : 1	5 : 1	6 : 1	6 : 1	6 : 1
Pitch . . .	1	1	$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{3}{4}$
Driving pulley .	18×4	18×5	21×4	21×5	24×5	24×5	30×5	30×6	36×6	36×8	42×8
Speed . . .	128	150	208	192	170	223	203	212	240	288	273
Output, tons per hr.	30	48	70	82	95	123	136	187	206	281	312
Speed, ft. per min.	200	250	300	300	300	350	350	400	400	500	500
Rubber and canvas belt ply . .	3	3	4	4	5	5	5	6	6	7	7
Solid woven canvas belt thickness .	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{3}{8}$
Size of longitudinal channels . .	$5\times2\frac{1}{2}$	$5\times2\frac{1}{2}$	$5\times2\frac{1}{2}$	6×3	6×3	6×3	$7\times3\frac{1}{2}$	$7\times3\frac{1}{2}$	$7\times3\frac{1}{2}$	$8\times3\frac{1}{2}$	$8\times3\frac{1}{2}$

All dimensions are in inches. The output is calculated on material weighing 50 lb. per cu. ft.

Where the inclination of a conveyor is very steep, its efficiency may be increased by fastening strips of wood or iron about 3 in. high at intervals of 3-4 ft. on the belt. These prevent the material from falling down the belt, and enable the conveyor to be used for an incline of 25 degrees, or a rise of nearly 1 ft. in 2 ft. Unfortunately, when such cleats or flites are attached to the belt it cannot run so smoothly as a plain belt, so that for very steep inclines bucket conveyors or drag plates (see later) are preferable, or, in some cases, vertical lifts are best.

Fixing Belt Conveyors.—Great care is necessary in putting on a new belt, in order that it may be mounted perfectly true, otherwise the wear will be excessive. As a matter of fact, it is very difficult to make a conveyor belt, or in fact any belt of great length, absolutely true and straight when stretched. Consequently, after it has been placed on the pulleys it should be started very slowly, watched carefully, and the tension put on very gradually; for it sometimes happens that the tail pulley has to be taken up more on one side than the other, and some of the intermediate carriers moved to the right or left, so as to adjust any inequalities in the belt. In making these adjustments great care is necessary, but when once the belt is adjusted it will usually continue to run true and give satisfactory service until worn out; if, however, the belt is set wrongly it is soon spoilt. Sometimes, in ignorance, steering idlers are applied to force the belt to run within certain limits; this is not good practice, as these idlers wear out the edges by exeessive pressure, and although the belt may be forced to run approximately true, it does so at an enormous cost in wear and tear. Steering idlers should only be used to prevent accidental sheering of the belt, and not for forcing the belt to run true.

If, after running straight for some time, a belt begins to run erratically, the whole conveyor should be carefully examined, as

any deficiency in the lubrication may make trouble by causing any one of the pulleys in a set of troughing idlers to run hard or to remain stationary. Perfect lubrication plays a very important part in the successful operation of a belt conveyor, and though self-lubricating devices should be used, they require frequent examination.

The most suitable troughing idlers, if these are necessary, consist of three pulleys, one horizontal and two side pulleys at a suitable angle. Care should be taken that the edges of the pulleys do not cut the belt.

In lacing a belt, the edges should be made to coincide and the centre of the belt fastened first. Then the edges of the belt should be secured and finally the spaces between. If metal fasteners are used they should be inserted one on one side and another on the other side, alternatively, until the whole width of the belt is securely fastened.

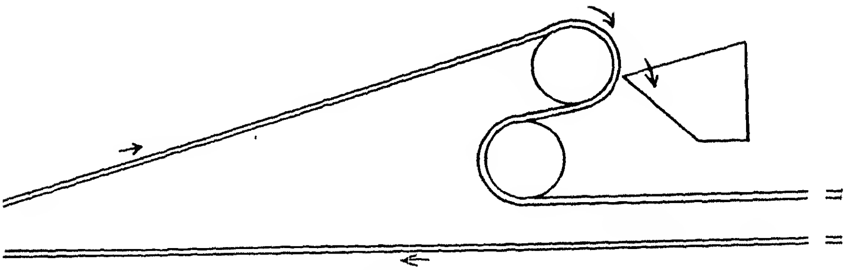


FIG. 55.—Diverter for belt conveyor.

Feeding Belt Conveyors.—In most cases, a chute or hopper is employed for supplying the material to the belt. Such a chute or hopper should deliver the material on to the belt at approximately the same speed as the belt travels, so as to avoid unnecessary abrasion. The shape of the chute should be such as to prevent the direct impact of the material on to the belt. In all cases, care should be taken that the chute cannot damage the belt during the feeding. It is undesirable, though sometimes necessary, to feed from two chutes on to the same belt, but this tends to overload the belt and also to cause unnecessary abrasion as a result of the material already on the belt coming into contact with a stream descending from another chute. Whichever type of chute is employed, it should deliver on to the centre of the belt so as to distribute it evenly over the surface of the conveyor.

Discharging Belt Conveyors.—If diverters (p. 330) are used, they should be arranged so as not to damage the belt, though they almost invariably cause increased wear and tear. A tripper (Fig. 55) which may be placed at any point on the belt and may be moved as desired is less likely to damage the belt.

Prior to stopping a belt conveyor, it is important to let it

;e the whole of its load ; otherwise, on restarting it, an
e amount of power may be required and this may cause
trouble. With a little forethought, no difficulty need be
.ced in taking this precaution.

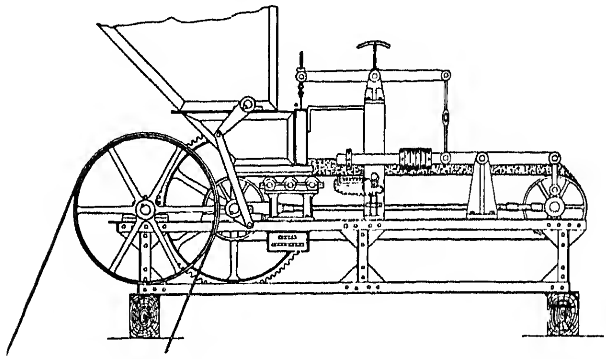
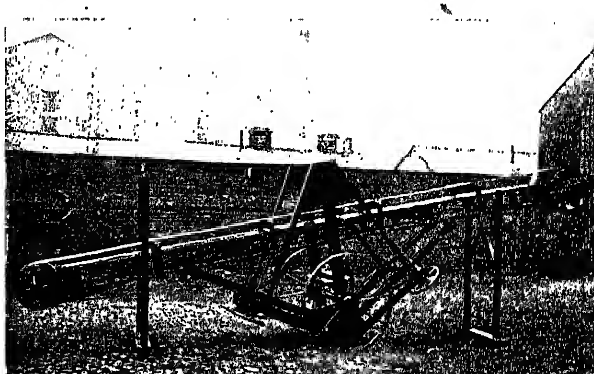


FIG. 56.—Poidometer.

Poidometers.—If desired, belt conveyors may be arranged either to weigh the materials which pass on to them or to supply definite quantities of materials on to the belt. This is effected by means of a poidometer, such as that shown in Fig. 56, which consists of a conveyor, mounted on a steel frame and prepared to receive the material from a cast-iron hopper above. The material

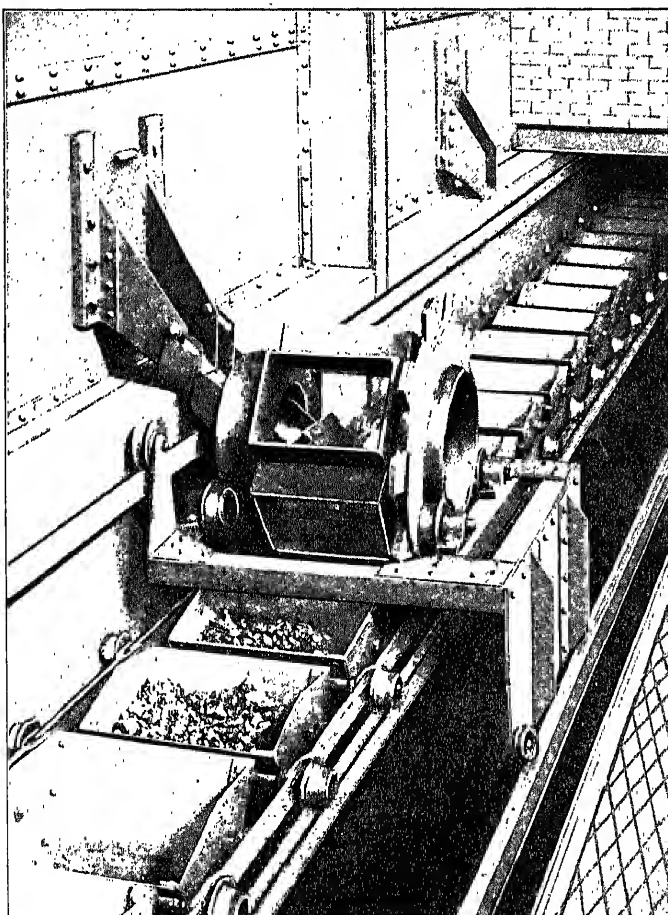


Hepburn Conveyor Co., Ltd., Wakefield.

FIG. 57.—Portable belt conveyor.

passing from the hopper on to the belt causes the belt to sag, so that its weight is borne by a supporting roller under the middle of the belt ; this roller pulls on the walking beam of a weighing machine, causing a reverse motion which is counterbalanced by

a weight on the scale beam, which, in turn, is a measure of the weight of material supported by the roller. Where a regular supply of material is required the motion of the beam is made to close or open the hopper gate so as to keep the delivery of the



R. Dempster & Sons, Ltd., Elland.

FIG. 58.—Bucket conveyor.

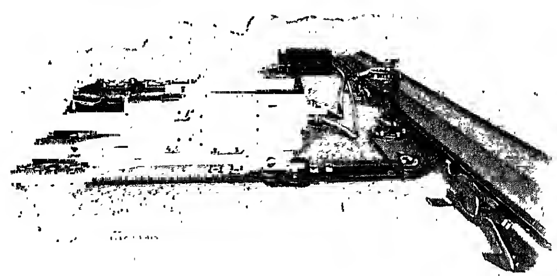
material constant relative to the weight indicated on the scale beam. By means of this apparatus it is possible to measure the amount of material passing over a belt (see also p. 326).

Portable Belt Conveyors such as that shown in Fig. 57 are sometimes of value for short distances. The design is practically the

same as for larger fixed conveyors, but a special oil-engine or electric motor is used and the whole apparatus is mounted on a movable body, so that it can be taken from place to place as required. When the material has to be conveyed in an upward direction, it is usually preferable to employ a bucket elevator, or a belt to which cross-pieces or " slats " are attached, to prevent the material from travelling backwards instead of forwards.

Bucket Conveyors (Fig. 58) consist of a series of buckets fitted with wheels and attached to each other to form a long endless chain. The buckets empty themselves as they turn over the pulley at the delivery end of the conveyor, or they may be made to tip at any desired point. In some forms of bucket conveyors the buckets are made to overlap. In another form the buckets are fixed to a belt at regular intervals instead of being linked together. (See also Fig. 41 and *Bucket Elevators,* p. 339).

Jigging Conveyors (Fig. 59) are sometimes very economical if the material is not plastic or sticky and the distance is not too



Diamond Coal Cutter Co., Wakefield.

FIG. 59.—Jigging conveyor.

great. They usually take the form of shallow troughs mounted upon arms, pivoted about their lower ends, and have a slight inclination to the vertical, sloping upwards in a direction contrary to that in which the material is to move. A small to-and-fro radial motion is given to these arms, which thereby first impart a slow forward and upward motion of about $1\frac{1}{4}$ in. to the trough, and then rapidly draw it down and back again. As a result of this action, the material proceeds forward in a series of small jumps which are, however, almost imperceptible, the material appearing to flow uniformly along the trough.

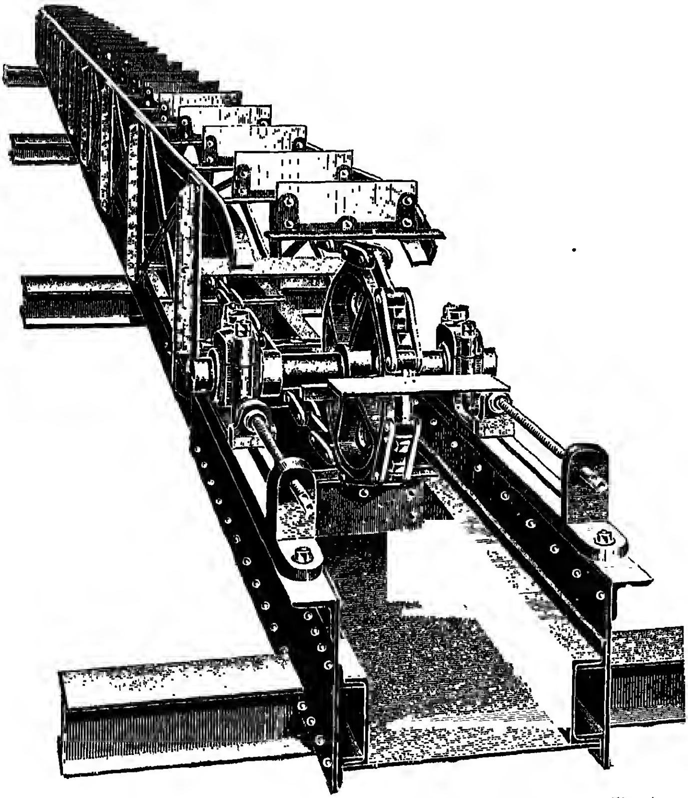
Long troughs should be divided at the centre and driven by cranks, arranged opposite to each other, so as to balance the apparatus and obviate unnecessary vibration.

The capacity of a jigging conveyor is obtained by multiplying the cross-sectional area of the trough by the speed in feet per minute. The speed of travel varies from 60 to 120 ft. per min. The power required to drive a jigger conveyor varies with different

types between wide limits, but is usually between 1/10 anc h.p. per foot-ton-hour.

A jigger conveyor has few moving parts, and all are simple readily accessible. If necessary such a conveyor can be used , screen, or as a drainer, though not so satisfactorily as some other types of screen.

Sprocket-chain Conveyors have two parallel chains in place of



R. Dempster & Sons, Ltd., Elland.

FIG. 60.—Scraper conveyor.

a belt, these chains carrying a series of trays or buckets. Such a conveyor (see Fig. 61) is chiefly used for inclines greater than can be handled with an ordinary belt conveyor.

Scraper or **Drag-plate Conveyors** (Fig. 60) consist of a fixed wooden or metal trough, above which runs an endless chain, to which are attached wooden or metal plates somewhat smaller than the cross section of the trough. The number of these plates or

scrapers depends on the desired capacity of the conveyor, and on the ease with which the material can be scraped along the trough; for sand they are usually about 2 ft. apart.

On setting the conveyor in motion, the plates are moved forward, dragging with them any material which may have been placed in the trough, and carrying it to the end. The plates then pass over the end-pulley and so back to the beginning of the trough, when they again draw the material forward. By providing suitable openings in the bottom of the trough, the material may be discharged at any point; otherwise it will be discharged at the end of the trough.

The disadvantage of this form of conveyor lies in the tendency of the plate to become jammed and to stick fast if the material is wet; otherwise it is a useful and very practical appliance for moving coarse sand and gravel. There is much friction on the inside of the trough as the material passes along it, with the result that not only is a considerable amount of power absorbed, but there is much wear and tear of the trough, and a great tendency to contaminate the sand with the material of which the trough is composed.

Drag-plate conveyors are chiefly used for very steep inclines where an ordinary plain belt would fail to carry the materials. They are not suitable for wet materials, as the adhesion of the latter causes an excessive consumption of power.

Table LXVII. shows the capacity of conveyors of this type.

TABLE LXVII.—CAPACITIES, SPEEDS, AND DIMENSIONS OF DRAG-PLATE CONVEYORS. (G. Mitchell.)

Width in Inches.	9.	12.	15.	18.	21.	21.
Capacity tons per hour of material 50 lb. per cu. ft.	8	11	16	20	30	40
End chain wheels	$15\frac{3}{4}$	$15\frac{3}{4}$	$19\frac{3}{8}$	$19\frac{3}{8}$	24	24
Trough channels (in.)	$5 \times 2\frac{1}{2}$	$5 \times 2\frac{1}{2}$	6×3	6×3	$8 \times 3\frac{1}{2}$	$9 \times 3\frac{1}{2}$
Speed (ft. per min.)	80	75	75	70	70	70

The capacity may also be calculated from the formula $C = \frac{ave}{d}$, where C is the capacity in cu. ft. per min.; a is the space in cu. ft. between two scrapers; v is the speed in ft. per min.; d is the distance apart of scrapers in ft., and e is a filling coefficient, dependent upon how much of the space between the scrapers is actually occupied by the material. It varies from 0·4 to 0·8.

The plates in scraper or drag-plate conveyors move at speeds varying from 60-120 ft. per min.

Bucket Elevators.—For raising sand from one level to another in cases where a belt conveyor cannot be used, a bucket elevator (Fig. 61) is of great value. It usually consists of a number of buckets placed at regular intervals along a band, or between two parallel endless chains, which run over pulleys placed at the head and foot of the elevator. The band may be of cotton, rubber, leather, or hemp; when chains are used they may be of the Ewart detachable type made of malleable iron. The pulleys for the leather and similar belts are of the usual crowned type, special sprocket wheels being used for the chains. Owing to the high cost, leather belts are seldom used.

The buckets may be of pressed steel or iron. When coarse materials are being conveyed, holes are made in the buckets for draining purposes. The shape of the buckets depends entirely on the kind of material to be elevated and in the slope of the elevator. It is very important that a well-designed type of bucket should be used; very small buckets tend to spill the material as they pass over the top pulley, and so decrease the output of the elevator and clog the mechanism by which it is moved.

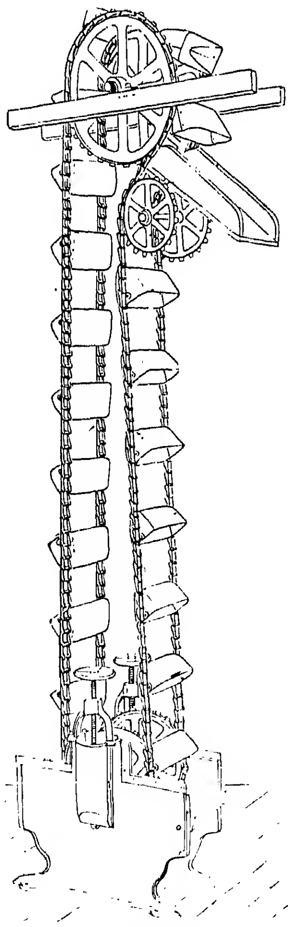


Fig. 61.—Bucket elevator.

The material should be fed into the buckets as they rise from the boot, or bottom casing of the elevator; it should not be delivered into the boot itself, but should be supplied about 2 ft. above it, as much power is wasted if the buckets are filled by ploughing through the material placed at the lower end of the elevator. The efficiency of a bucket elevator depends on a constant and regular feed, so that it is preferable whenever possible to employ an auto-feeder.

The discharge takes place beyond the head of the elevator and should be so arranged that the material from one bucket falls clear of the preceding bucket. In some vertical elevators the carrying chains are placed at the sides of the buckets, and, after passing round the larger head sprockets, are bent back by smaller snub sprockets to ensure a clean delivery. This is

avoided if the conveyor is steeply inclined instead of being quite vertical.

Continuous bucket elevators are so arranged that there is no intervening space between the buckets, the back of one bucket forming a chute for the delivery of the material in the following bucket. This type of elevator has the further advantages that the material may be fed in at various points and not only at the foot, and also that breakage of the material is greatly minimised. The bucket flights are generally supported by flat bars which run upon renewable steel or cast-iron wearing strips.

Elevators should be enclosed in a wooden or sheet-iron casing, doors being fitted for inspection purposes. The foot or boot should be fitted with screws to take up the belt or chains when they become slack.

The capacity of elevators is given by :

$$\text{tons per hour} = \frac{V \times e \times C \times w}{37{\cdot}3d.},$$

where V = speed in ft. per min., C = capacity in cu. ft. of one bucket, w = weight per 1 cu. ft. of material, d = distance apart of buckets, and e is a constant depending upon the filling capacity of the bucket; it varies from 0·5-0·75. Hence the amount of material delivered by a bucket elevator is usually 50-80 per cent of the theoretical output calculated on the capacity of the buckets.

In common with most conveyors, the speed of the elevators depends upon the material. An average speed for coal is 90 ft. per min., for ore and similar materials 90-120 ft. per min., for clay 200 ft. per min.

The power required may be taken as follows :

$$\text{H.P.} = \frac{15\ \text{WH}}{10{,}000},$$

when W = tons per hour elevated and H = the height to which the material is to be lifted, but double this power should usually be provided.

Elevators may be driven through belts, chains, spur- or chain-gearing, the drive being arranged at the head of the elevator. Where belt- or chain-drives are employed, they should be of less strength than the elevator chains, so that in the event of a breakage, due to overload or other causes, the driving chain would fail first and thus save the elevator chain—the advantages being obvious.

Road Traction, whether by horse and cart or by the more modern traction engine or motor van, is usually cheaper for local deliveries than the railway. The most convenient type of cart is an ordinary tip-cart of about 2 cu. yds. capacity, but if the district is very hilly a smaller cart containing only $1\frac{1}{4}$ cu. yds. may be more convenient. Horses and carts are not economical for distances above three miles; motor lorries are economical up to about 40 miles;

above this distance the railway is cheaper, though if there is a moderately long distance between the railway and the site to which the material has to be delivered, it may be cheaper to send it throughout the whole distance by motor.

Traction engines and motor lorries are much more suitable than horse wagons for sand pits, stone quarries, etc. The roads must be suitable, however, and kept in good condition, or the wear and tear on the machines is excessive. For loads over 10 tons, steam wagons are generally more economical than those with oil engines. A motor wagon driven by producer gas appears to offer several advantages. Oil-driven motor lorries are unsuitable for weights over 6 tons, owing to the wear and tear on the wheels and engine. They are preferably built of steel with riveted spokes.

The driver should be a skilled motor mechanic, capable of telling from the beat of his engine whether anything is the matter, and if so, of repairing it at once. This means higher wages than are paid to horse drivers, but the increased output of the motor compared with that of a horse and cart will compensate largely for this. It is strongly to be recommended that all motors and traction engines in regular work should not be used for more than five working days, and should be thoroughly overhauled on the sixth day; including such repairs as re-boring cylinders, re-tubing the boiler and other more extensive repairs, it is not safe to reckon on more than 240 working days per year.

It is almost impossible at the present time to institute a really reliable comparison of working costs and standing charges of horses and carts with other forms of traction, as so much depends on local conditions. The question of depreciation also complicates the problem. It is probably correct to write off one-quarter of the cost of a motor wagon at the end of the first year, and at the end of each succeeding year to take off a quarter of what is left; thus a motor wagon costing £800 would depreciate to £600 at the end of the first year, to £450 at the end of two years, to £190 at the end of five years, and after eight years' use it would have on the books only one-tenth of its original cost. This method of calculating the depreciation is much safer and fairer all round than the more usual one of writing off 10 per cent of the original cost each year. In estimating the cost of motors and engines with a view to comparing the different types in use, errors of considerable magnitude often creep in, owing to the careless way in which repairs are not charged to the transport but to a general account for the whole works. The wisest course is to open a separate bank account for the motor wagon or steam engine with its attendant trailers, to pay all expenses in connection with them out of this account, and to place to its credit all sums received for the delivery of the material.

In consequence of the expenses of repairs, many firms now sub-let all their carting to engineering or other firms, at a rate depending on the load and the distance, and in this way save

themselves the worry and responsibility of repairs and depreciation. For establishments of moderate size this plan is to be commended.

It is generally found that for journeys of 20 miles or more a load of 4 tons on a motor is more economical than the use of horses and carts. For shorter journeys, the load multiplied by the journey must not be less than 60, so that the critical point is 5 tons for 12 miles, 6 tons for 10 miles, and so on, though with improved construction this may be reduced. For a number of journeys in quick succession and on good roads, a 6-ton lorry when fully loaded should be able to make at least four journeys of five miles each in a day, but much depends on the facility with which it is loaded and unloaded. The use of additional bodies, which can be lifted on and off the chassis by means of a crane, greatly facilitates loading. Special care is required to ensure a minimum amount of time being spent in loading and unloading, as during this time the driver's wages and the interest and depreciation charges on the lorry are earning nothing.

As regards the size and type of motor, it may be taken roughly that loads under 5 tons are most economically carried on the motor itself, but larger loads are best distributed between the motor and a trailer. The relative advantages of oil (petrol or paraffin) over steam are most marked in the smaller loads (10 tons and under), and are chiefly due to economy of power-production per ton-mile, to the rapidity of starting, and to the smaller cost of attendance. For larger engines, the cost of petrol is too great for economy, but if an engine burning heavy oil could be constructed, or producer gas could be used, the adoption of the heavier type of motor wagon would make progress.

Water carriage is deservedly popular where it is feasible, as it is cheap. The chief disadvantages of this means of transport are the low level at which the material must necessarily be delivered and the slowness of the transit.

Railways form the chief means of transport over long distances, and for economical working it is, therefore, advisable to have a siding in the yard whenever possible. Miniature railways are a feature of some sand pits and quarries, the locomotives being driven by steam, oil, or electricity, according to local conditions. With the rapid increase in the general use of petrol motors, their application in the quarry is only a matter of time. They are excellent for loads up to about 5 tons, but for greater loads small steam-driven locomotives or electric motors are usually cheaper in use, though not in the first cost. When the delays connected with arranging large numbers of wagons into trains and redistributing them are considered, it is often found that several smaller motors driven by youths will move the material more rapidly, more conveniently, and at less cost than a locomotive.

Mechanical Equipment in Sand Pits and Quarries

At the present time, both hand labour and mechanical appliances are so dear that many owners of sand pits or quarries are in a quandary as to what course to pursue. Energetic and persuasive travellers representing firms who manufacture labour-saving appliances are naturally more interested in the sale of these devices than in the precise amount of saving to be effected by the purchaser. On the other hand, there is no one to send out travellers to put forward the case for the employment of hand labour, and consequently its merits are apt to be overlooked. It is, in fact, of the greatest importance when considering labour-saving machinery to ascertain exactly what economy will follow. No two cases are the same, and in every instance where mechanical plant is contemplated, local circumstances may affect the case one way or the other. Wages are about double the pre-war figure and the hours are reduced by about 11 per cent. Machinery costs 150 per cent more than it did in 1914, repairs and spare parts have risen in proportion, while with financial conditions as they are at the moment, it is not always possible for a firm to meet a new heavy capital expenditure. Even where the additional capital is available, it does not always pay to invest it in mechanical appliances. Thus it would not pay to purchase a steam navvy to dig and load 20,000 tons of sand, but for a much larger quantity—say 150,000 tons in ten years—a steam navvy (including full repayment of capital and repairs) costs less than half the amount which would have to be paid for hand labour.

One advantage of mechanical handling lies in the less extent to which manual labour has to be relied on, the lesser dislocation which follows on strikes, and on the greater contentment of the few m[illegible]. as the higher wages earned place them in a more [illegible] position. On the other hand, machinery is not necessarily more reliable than hand labour, and it is particularly harassing to find that the whole of the works may be seriously disturbed by the sudden breakdown of some more or less trivial detail in the mechanical part of the plant.

The principal considerations which each manager should apply when considering replacing hand labour may be briefly enumerated as follows:

(*a*) Can the cost of working be curtailed, and if so, what will be the annual saving?

(*b*) Will better working result, or greater output follow the introduction of machinery? If a greater output is obtained from the plant already in use, what will be the effect in wear and tear?

(*c*) Is the saving effected by (*a*) and (*b*) likely to be sufficient for meeting the standing charges for repayment of capital at 5 per cent interest, and also for depreciation and repairs?

(*d*) Will efficiency be sacrificed in order to effect an apparent economy?

(*e*) Will the reduction of labour relieve the management of any anxieties not actually measurable in money ?

Considerations of capital charges are perhaps the most important matter to be settled in replacing hand labour by machinery. In other words, what capital outlay is permissible in order to save the wages of a single workman ? In the majority of cases the men displaced will be ordinary labourers paid at the lowest rates, for mechanical labour-saving machinery seldom does the work of a skilled craftsman paid at the special rates ruling for his trade. Moreover, the attention demanded by machinery involves the introduction of skilled labour to operate and repair it. Including outgoings in the way of tools, National Insurance, holiday pay, and in some few cases profit-sharing or other forms of bonus, the expenditure per labourer per annum amounts to approximately £200. The annual charges on the capital cost of new machinery, including interest, wear and tear, depreciation, or the writing off of capital, amount to a total of 20 per cent per annum. Now the £200 which is equivalent of a labourer's total cost, represents the interest at 20 per cent on an outlay of £1000, so that it may be assumed as a general statement that if the work is continuous for five years or more, the capital outlay permissible on mechanical plant may be reckoned at £1000 per man displaced by it. This figure indicates that in cases where a permanent reduction of ten men or more can be foreseen, comparatively large schemes may be undertaken. It is the smaller schemes, in fact, which demand the most thorough scrutiny, for with them the delays due to machinery not working properly are the most serious. In considering the figure £1000, the cost of fuel or driving power, lubrication and attention to the machinery must not be overlooked. Assuming that these cost only 12s. per week, it would reduce the permissible outlay to £900. In most cases a much more elaborate calculation is necessary, as the whole of the costs of working the machine and the capital charges must be ascertained ; an allowance for times when the machine is out of order, and for when there is no work for it, must be added (for no saving can be made by trying to put a machine on " short time " like a labourer), and from the figure so obtained a fairly accurate comparison may usually be made.

The best method of calculating the capital charges is to decide how many years the machine may be expected to work at full speed, without an excessive charge for repairs (ten years is usually a maximum), and then to inquire of an insurance company, what would be their charge for an endowment policy for the cost of the machine, the policy to be payable in the given number of years. The annual charge required by the insurance company may be taken as the sum which would be charged to the machine to cover interest on capital, repayment of capital, and depreciation—in short, the capital charges.

There are of course many operations which cannot be effected

so cheaply mechanically as by hand labour, but the wise manager always should realise that a simple machine of any automatic character, which is reliable in its action and is kept constantly at work, will be cheaper and more dependable than a man, if the machine cost £850 for each man it displaced. Hence, if a machine costing £2500 is contemplated, it must actually, at that particular works and under conditions then prevailing, displace at least three men if it is to be of direct financial benefit. If a man is required to work the machine, then at least four men and probably five should be displaced before the machine is profitable.

It is most important to observe that it is the average performanee of a machine at the purchaser's works which defines its value to him. Thus, a steam navvy may have an output of 15 tons per hour, or 720 tons per week, but if it is only required to move 100 tons per week, it will not pay to use it in most works where labour is available. A similar argument applies to many other labour-saving devices; they are only profitable when fully employed for at least 80 per cent of the working week, during a period of eight to ten years. Where a mechanical handling device is operating at less than 80 per cent of its rated output, it will only justify its installation in circumstances which cannot be justifiably termed "usual" ones. For this reason, whilst quarry managers and others should always retain an open mind with regard to the use of machinery, they should also remember that there are many conditions in which human labour is cheaper, especially where the work is of an intermittent or irregular character, as men can be put to other work, placed on short time, or even "suspended," but a machine, once it has been purchased, involves the same capital charges when it is idle as when it is fully at work.

CHAPTER VIII

CRUSHING SAND-ROCKS AND GRINDING SAND

After the material has been quarried and transported to the plant, it is treated in various ways in order to prepare it for the particular purposes for which it is to be used. The nature and extent of this treatment depends largely on the original materials and the use which is to be made of the sand.

The various treatments whieh may be necessary—one or more of them being used as required—may be summarised as follows :

1. Crushing and grinding.
2. Purifieation.
3. Drying.
4. Sereening.

All these treatments are seldom neeessary for any one material, nor need they be earried out in the order shown above. Thus, whilst crushing or grinding is generally necessary for materials whieh occur in large pieees, loose, incoherent sands do not, of eourse, require this treatment. Only certain sands require to be purified ; most sands are used for such purposes that they are quite satisfactory without any purification. Again, only those sands which have been dredged or recovered from below water, or those which have been washed, will require to be dried, and for many of these no special drying process is needed so long as the surplus water is allowed to drain away. Screening is necessary in the case of most sands and is seldom omitted.

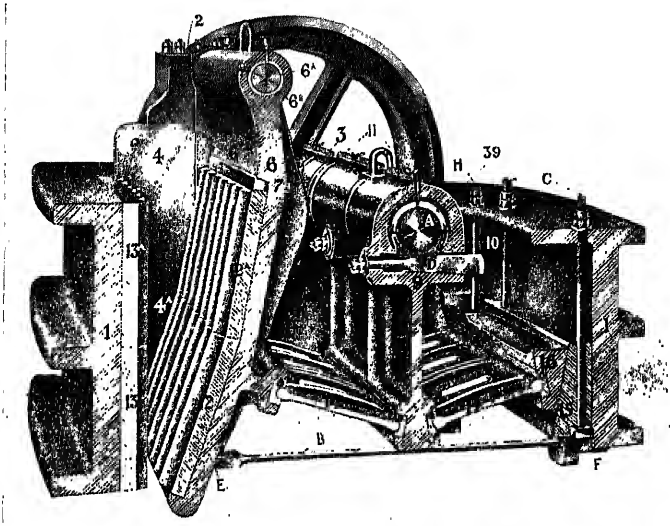
Crushing

Where a sand is to be obtained from large pieces of quartzite, sandstone, ganister or silica rock, it is necessary to crush the material in order to reduee it to the requisite fineness. This reduction of roek is usually divided into two types of operation : (*a*) *crushing* the material to pieees $\frac{1}{8}$–1 in. in diameter, and (*b*) *grinding* the erushed pieees to the desired size. This subdivision is rendered necessary by the faet that most fine-grinding mills would be rapidly damaged if fed with eoarse material, and apart from this, the

output would be low and the grinding costly. By effecting the grinding in two stages a maximum output with a minimum amount of wear and tear is obtained.

The coarse crushing of massive sandstones and silica rocks is difficult and costly on account of their great hardness, which causes wear and tear on the machines, and necessitates the use of very strong and durable crushers and the expenditure of a considerable amount of power, so that both skill and ingenuity are required to crush such rocks to a suitable size as economically as possible.

Soft and partially decomposed sandstones may be of all degrees of hardness less than that of the grains of quartz of which they are composed; such sandstones are reduced much more easily than the harder quartzites and at a smaller cost, so that they present less difficulty.



Hadfields, Ltd., Sheffield.

Fig. 62.—Jaw-crusher.

The principal machines used for crushing sand rocks are stone-breakers, gyratory crushers, and disintegrators. Stamps were formerly used, and are still employed in some localities for brittle rocks; though their action is that of grinding rather than crushing, because it has been found that they seldom work economically on pieces larger than 4-in. diameter, they are now more largely used to produce a moderately fine powder than as preliminary crushers. For this reason, they are described in the section on Grinding.

Stone-breakers or **Jaw-crushers** consist essentially of two jaws composed of hard steel, one fixed and the other movable. A typical jaw-crusher is shown in Fig. 62. By means of two powerful

flywheels, one on either side of the machine, connected by toggle gearing to the movable jaw, the latter may be made to approach or to recede from the fixed jaw, thus crushing any lumps of material placed between them. On account of the excessive wear and tear on the jaw-plates in the ordinary crusher, these latter are so made that they can be removed when worn and replaced by new ones. As the lower ends of the jaws have the greater part of the work to do they wear much more quickly than the upper parts, so that the jaw-plates should be made so as to be readily taken out and reversed. The jaw-faces and cheek-plates are of chilled cast iron or preferably of manganese steel backed with a white alloy. The toggles and cushions should be of hardened steel, as they are called upon to resist heavy stresses.

Numerous attempts have been made to design a jaw-crusher without toggles, but for really hard work, and the consequent severe strains on the machine, those crushers in which toggles are embodied have more than held their own. In one type of machine the swinging jaw has arms at the back supporting a roller against which bears a removable cam secured to the driving shaft.

It has been found that by making the face of the movable jaw a segment of a circle instead of flat, a finer product is obtained because the material is subjected to a squeezing or rolling action in addition to the simple crushing.

It is often an advantage to have two sets of ribs on the faces of the jaws ; one set of ribs projects out further than the others near the top of the jaws, and so applies the pressure earlier than when all the ribs are of the same size throughout. The result is crushed stone of more uniform size. Stone-crushers having this arrangement are sometimes known as *granulators*. In some crushers the movable jaw is given a joggling as well as a to-and-fro motion ; this draws the material more effectively between the jaws and reduces the slipping to a minimum. In one very simple design of jaw-crusher the power is transmitted from the crank-shaft to the oscillating jaw through a lever and through a roller mounted between the lever and the jaw. The jaw has a concave face at the back upon which the roller moves without any need of lubrication. It is claimed that this method of driving has a greater efficiency and requires less driving power than the ordinary jaw-crusher, whilst the wear is reduced to a minimum on account of the smaller number of bearings and the smaller pressure upon each.

Some American users prefer to have one swinging jaw and one toothed roll in their crushers, and maintain that this arrangement is cheaper in power. The author has never been able to make an accurate comparison of the merits of these two types.

The size of the stone-breakers varies greatly according to the output required. Hadfields, Ltd., of Sheffield have built machines with openings up to 4 ft. 6 in. long and 3 ft. wide, which will take pieces of stone weighing as much as $1\frac{1}{2}$ tons and produce about 150 tons of crushed stone per hour, but for most quarries a crusher

which will deal with pieces about 12 in. × 12 in. × 12 in. is sufficiently large. No crushers are remunerative unless kept fully employed, and the number of works which can keep a very large crusher continually in use is very small.

The power required by jaw-crushers is shown in Table LXVIII.

TABLE LXVIII.—POWER REQUIRED BY JAW-CRUSHERS

Upper Opening between Jaws (in inches).	24 × 16.	20 × 9.	16 × 8.	12 × 8.	8 × 5.	8 × 4.
Output (in cubic feet) . .	352	212	148	106	70	52
Horse-power required . .	14	10	7	5	2	$1\frac{1}{2}$

Stone-breakers with cam and roller action require rather less power than the ordinary type for the same size of machine.

It is most important that a sufficient provision should be made in the power supplied, in order to allow for the great strains to which the machines are subjected when large pieces of material are fed into the crushers. The figures given above are more than is required for ordinary working, but less power should not be provided, otherwise a man may have to be employed for crushing large pieces of stone, so as not to damage the machine. Too little power may also cause a sudden breakdown which would be much more expensive in the long run than the provision of greater power for driving the machine.

The jaw usually moves from $\frac{1}{8}$-$\frac{1}{2}$ in. and the flywheel usually makes 250-300 revs. per min., the number of oscillations of the movable jaw being from 250-300 per min. An excessively high speed is undesirable owing to the bearings of the breaker becoming too hot and causing a great deal of wear and tear. Some of the small Sturtevant stone-breakers (8 in. × 12 in.) are run at speeds varying from 170 revs. per min., whilst the larger breakers (18 in. × 30 in.) run at 130 revs. per min.

The size of the crushed material delivered by a jaw-crusher depends on the space between the lower ends of the jaws; this may usually be varied between fairly wide limits. It is important to adjust the lower opening between the jaws so as to suit the material; if the jaws are set too closely together they will produce too much powder and will waste a large amount of power. The pieces of crushed stone usually vary from about 6 in. diameter down to about $\frac{1}{2}$ in. diameter. For crushing below $\frac{1}{2}$ in. diameter, stone-breakers and other coarse crushers are not economical on account of the power required. It is preferable, where fine material is required, to crush down to about $1\frac{1}{2}$ in. in a coarse crusher, such as a stone-breaker, and then to reduce the material further in a fine grinding machine. It is also important to avoid crushing large pieces of stone too much in one machine, as much less power is

used if the largest pieces are reduced to a medium size (3-4 in.) in one crusher, and then to a smaller size in a second jaw-crusher. Thus, blocks 18 in. or more in diameter may be reduced to about 10 in. in the first crusher ; these smaller blocks may then be reduced to $4\frac{1}{2}$ in. in a second crusher, the product from which is then reduced to say 1 in. material in a third crusher.

A considerable saving in the amount of power required may also be effected by passing the stones over a screen or grid before they enter the crusher ; this separates the smaller pieces which do not need crushing, or by using two screens the pieces too large for the medium crusher may also be separated and either broken by a sledge hammer or sent to a larger crusher.

The output of jaw-crushers is a little less per horse-power than the output of gyratory crushers, when the size and hardness of the material are equal in both cases and they are reduced to the same degree.

Gyratory Crushers have crushing surfaces in the form of two cones, one inside the other, the outer one being inverted. The stone to be crushed is dropped between the two cones whilst the inner cone is rotated rapidly with a slight eccentric motion. The rock is crushed between the two cones, the crushed material falling through the annular space between them, on to a chute which brings it to an outlet at one side of the machine.

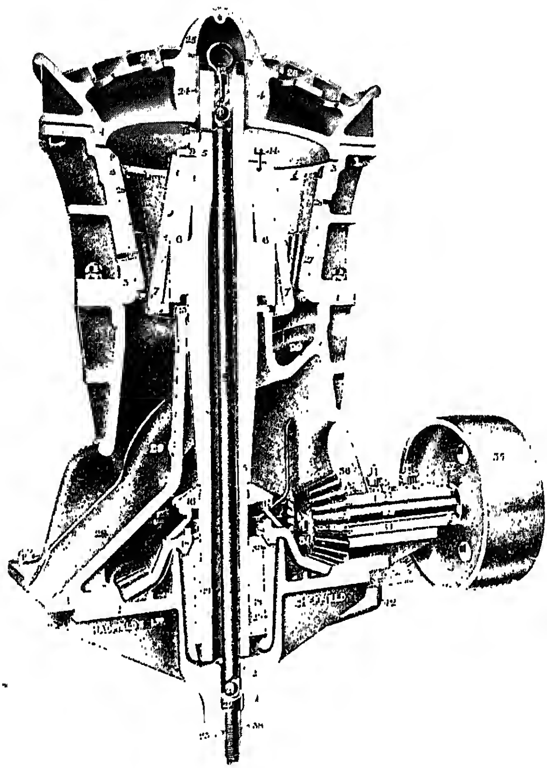
Fig. 63 shows a gyratory crusher made by Hadfields, Ltd. ; the lower portion, base plate and oblique diaphragm are made of cast iron and the upper portion of cast steel ; the cones are faced with manganese steel. The inner cone is mounted on a hollow shaft which gyrates in an anti-friction metal bearing, the upward thrust being carried by a bronze ball at the top of the shaft. The eccentric motion of the inner cone is produced by means of a crown and pinion gearing and an eccentric bearing. Small adjustments in the size of the product are made by raising or lowering the inner cone by means of a worm and worm wheel, thus varying the size of the opening between the inner and the outer cones, but it is best to have the machine designed for a definite product and to confine the adjustments to making good any variations in the size, due to wear and tear. Duplicate parts should always be kept in stock.

In a gyratory crusher the greatest strength is required in the main shaft carrying the inner cone ; this shaft should be of ample diameter and not too long.

The output of a gyratory crusher depends on its size, the size of the pieces put into it, the size of the finished product, and the nature of the material. As a rule, about 1 ton of 8-in. material may be made to pass through a ring $2\frac{1}{2}$ in. diameter for each 1 h.p. used in driving the machine. Machines with outputs of 200 tons per hour can be run even more economically, only about $\frac{1}{2}$ h.p. being required per ton of product. This is rather greater than the output of a jaw-crusher. Very large machines are, however, undesirable ; where a large output is required, it is preferable to

employ a number of machines each crushing about 50 tons per hour, rather than one large one, so that if one machine breaks down, the whole plant is not held up thereby.

It is most important to the economical working of the machine that the lubrication should be satisfactory. Automatic lubrication is preferable, and is much more reliable than trusting to the men in charge to supply the lubrication at suitable intervals.



Hadfields, Ltd., Sheffield.

FIG. 63.—Gyratory crusher.

From its appearance, a gyratory crusher might be thought to be a grinding machine, but this is not the case. The to-and-fro motion of the disc exerts a true crushing action ; the product from the machine is largely cubical and free from flat pieces.

Gyratory crushers, like jaw-crushers, are preliminary breakers and are not suitable for reducing stone to powder or even to " peas." The largest crushers should not be expected to produce pieces less than 4 in. diameter, although there will always be a small portion (up to 15 per cent) less than this size. The smaller crushers will

satisfactorily reduce rocks to pieces ½ in. in diameter with about 20 per cent of material below the size.

Gyratory crushers have many advantages, but they are subject to the following drawbacks :

(1) The working parts of a gyratory crusher are not so readily accessible as those of jaw-crushers, as they are enclosed in the casing of the crusher, whereas a jaw-crusher is quite open. For this reason, repairs are less easily effected in the gyratory type, the machine having to be taken to pieces each time a repair is made.

(2) Renewals and repairs to gyratory crushers are more expensive than to jaw-crushers on account of the greater cost and more intricate shape of the wearing parts.

Disintegrators are of three types :

(i.) Those which consist of a rotary shaft fitted with a series of fixed or loose hammers in a strong casing, and, by delivering a rapid succession of blows on to the material (which rests on a curved grating), disintegrate it into small pieces which fall to the bottom of the casing and may be collected through a discharge opening in the base.

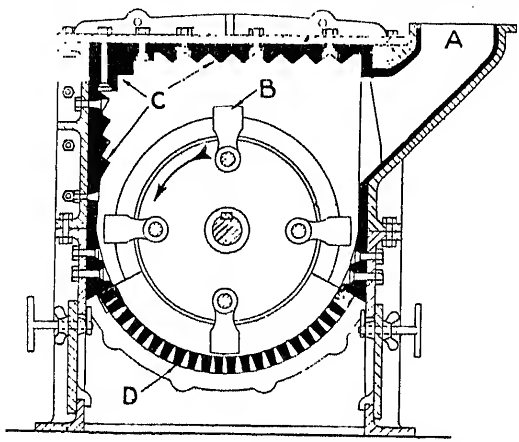
(ii.) Those which consist of two " cages," one or both of which revolve and so effect a disintegration of the material.

(iii.) Those which consist of beaters revolving in one direction surrounded by a cage which revolves in the opposite direction.

Bar disintegrators crush the material by the centrifugal force applied by rapidly rotating bars which are fitted to a shaft having a speed up to 3000 revs. per min. These machines may be used for a long time without need of repair, as they are very simply and strongly made. The beaters should be easily replaced if broken, otherwise the cost of repairs may be serious. They should be loosely attached to the axle so as to stand straight out by centrifugal action in the ordinary course of grinding, but to fall back when a particularly hard piece is encountered, as, otherwise, the machine may be damaged. This method is employed in the Mansfield Disintegrator (Fig. 64) made by F. Mansfield & Co., Liverpool, and in a similar machine made by the Sturtevant Engineering Co., Ltd. Both these machines are capable of crushing down to 10 mesh, and require about 5-10 horse-power per ton of material reduced to this size per hour. The hammers rotate at 1000-1500 revs. per min.

Usually the hammer bars are quite straight and tangential to the axis of rotation, but in the " Rapp Revivifier " disintegrator (Figs. 65 and 66) made by the Link-Belt Co., Chicago, Ill., U.S.A., the bars are fixed at an angle (like the blades in a pug-mill) so as to throw the material from each side to the centre of the machine where a curtain of round bars is placed. The purpose of this arrangement is to increase the mixing power of the machine and produce as homogeneous a mixture as possible. As a further precaution and to prevent the clogging of the bars, the casing and suspended rods are mechanically jolted ten times per minute by

means of a cam which raises the casing and then allows it to drop on to a wooden buffer. This machine is particularly suitable for

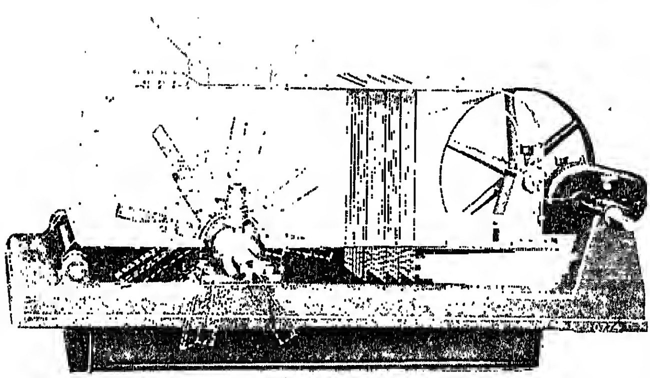


F. Mansfield & Co., Liverpool.

FIG. 64.—Disintegrator

treating old moulding sand and also as a combined mixer and crusher.

In the Lightning Crusher made by the Lightning Crusher and Pulveriser Co., Ltd., 14A Rosebery Avenue, London, E.C.1, the



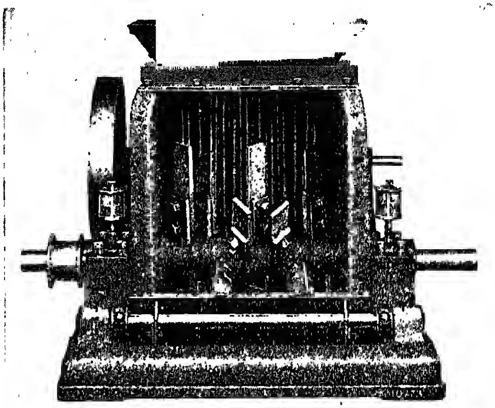
Link Belt Co., Chicago, U.S.A.

FIG. 65.—Rapp revivifier.

rotating shaft carries two discs to the periphery of which are attached four goal-shaped hammer bars. The makers claim that this arrangement renders clogging almost impossible, and that foreign

material, such as iron bolts, etc., accidentally introduced with the feed has no injurious effect.

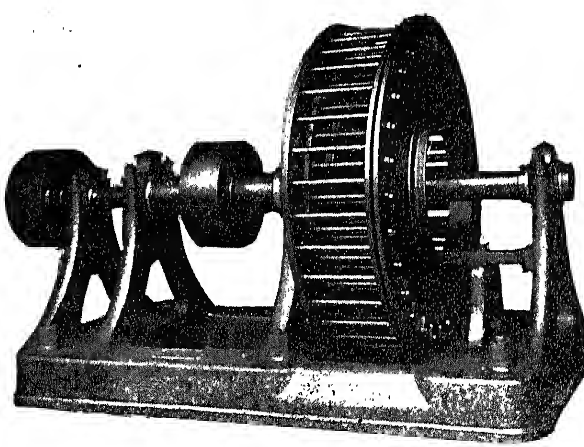
A bar disintegrator will crush three times as much stone as a



Link Belt Co., Chicago, U.S.A.

Fig. 66.—Rapp revivifier.

jaw-crusher of equal size, and yet will require rather less than 1 h.p. per ton of crushed material.



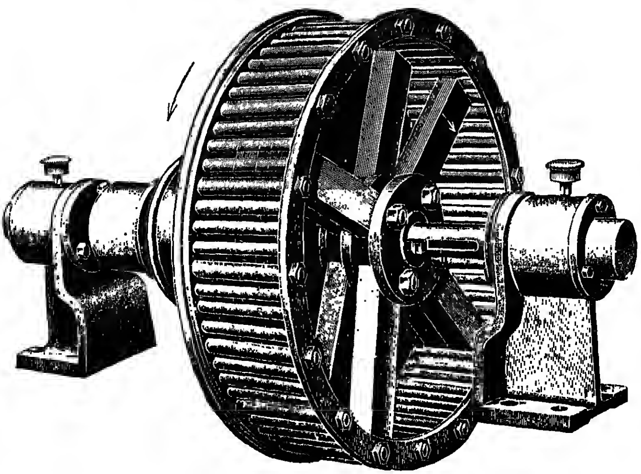
Bickle Engineering Co., Ltd., Plymouth.

Fig. 67.—Cage disintegrator.

Cage Disintegrators consist of two or more concentric cages (Fig. 67) constructed of steel bars arranged to form slotted drums. The first and third of these cages rotate in one direction and the

second and fourth in the opposite direction. The material is fed through a hopper into the centre of the innermost cage, and as the cages revolve the pieces of stone are struck by the bars of the cages and are broken; they then pass between the bars into the next cage, which revolves in the opposite direction, and the bars in this strike the fragments with double force; this operation is repeated by the bars of the remaining cages. The speed of revolution is very high (sometimes as much as 3000 revs. per min.), and in order to avoid harmful vibration the machine must be kept well balanced.

A combined bar and cage disintegrator consists of an outer revolving cage type, with beaters or hammer bars inside to secure



C. E. V. Hall, Sheffield.

FIG. 68.—Bar and cage disintegrator.

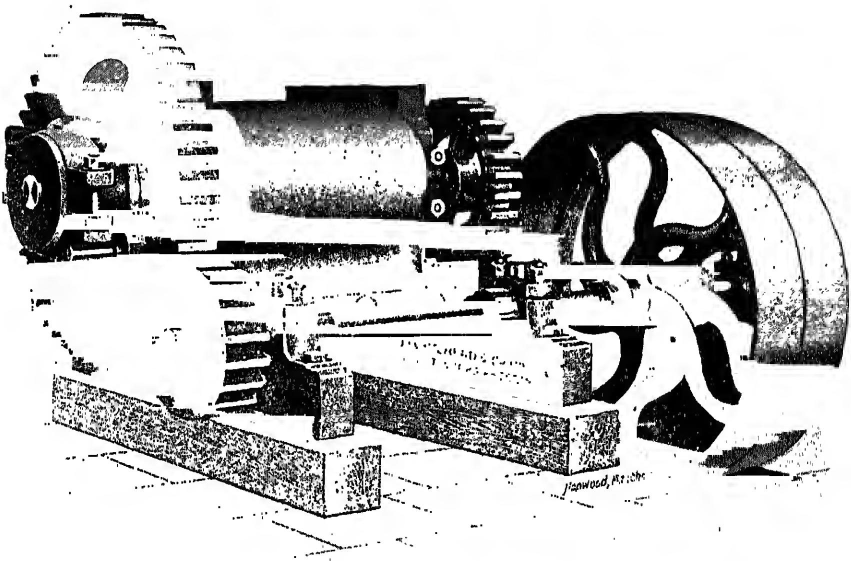
the rapid disintegration of the rock. This type of machine (Fig. 68) is made by C. E. V. Hall, Sheffield.

Disintegrators work most satisfactorily when supplied with pieces 3 in. or less diameter. They will crush economically to pieces $\frac{1}{16}$ in. diameter, but below this size they are wasteful in power; for further reduction a fine grinding machine is therefore necessary, unless the material to be crushed is of such a nature that it falls to powder on heating; some sandstones are of this nature and, after calcination, can be rapidly and cheaply reduced to powder in a disintegrator.

Disintegrators are also useful for crushing damp materials which would be "sticky" and troublesome in other types of crusher. They sometimes effect a partial drying of the material, as the rapidly rotating mechanism draws a large volume of air through the machine, after the manner of a ventilating fan.

As all disintegrators produce a great volume of dust, owing to the rapid motion of the air passed through them, it is usually necessary to discharge the product into a chamber, one wall (or the roof) of which is made of canvas or similar material, through which the air, but not the ground material, can pass. This canvas will require beating at intervals to remove the adherent dust, and it should be at some distance from the discharge outlet of the machine, or the force with which the material is delivered will rapidly cut it to pieces.

Crushing Rolls (Fig. 69) are sometimes employed as preliminary



J. Whitehead & Co., Ltd., Preston.

FIG. 69.—Crushing rolls.

crushers for reducing rock to small pieces which can afterwards be conveniently dealt with in other grinding machines. These rolls consist essentially of a pair of strong cylinders or rollers, which are placed side by side, so that when the material is fed on to them the rotation of the rolls forces the material downwards and reduces it to a size comparable to the distance between them. The rolls are usually driven by a simple gearing through a belt or clutch, but fast-running rolls are sometimes driven direct by two belts, each on a separate pulley, attached to each roll.

Crushing rolls must be very strongly built, in order to withstand the sudden strains to which they are often subjected in use. They should therefore be mounted in such a manner as to with-

stand very sudden and severe shocks, and should be provided with safety clutches or some other device to prevent accident in case a bolt or other article of exceptional hardness enters the machine.

Powerful springs, which are compressed when an abnormally hard piece of material enters between the rolls, are sometimes used, but are not really satisfactory, as they usually yield too readily and produce too coarse a product. They are better replaced by safety clutches fitted with a pin which breaks when a danger point is reached. Rubber buffers have been used to take up the strains, but they are unsatisfactory and should not be employed.

The shafts carrying the rolls are also subjected to very great stresses and should be made of the best quality axle steel. They should be of ample diameter, so as to be sufficiently strong, and they should be properly balanced, or accidents may occur when they are driven at high speeds. It is also necessary that they should be mounted in long bearings lined with phosphor-bronze bushes, as white metal wears too quickly in this class of machine unless it has a very large proportion of tin present.

The bearings should be kept in good condition, or the distance between the rolls may vary as they revolve, thus giving a product of irregular size.

The flywheel should be of large size ; small ones are inefficient on account of their irregular working when large or hard pieces of material are supplied to the mill.

All parts of the machine must be properly lubricated, otherwise a great waste of power may occur and the bearings may require frequent renewal.

The speed of crushing rolls varies considerably. Toothed rolls may be driven at 200-250 ft. per min. (equivalent to 48-60 revs. per min. with 16-in. rolls), but smooth rolls are sometimes driven at $2\frac{1}{2}$-3 times this speed, speeds up to 1000 ft. per min. being used. A good method of estimating the most suitable speed at which the crushing rolls should be driven is by the use of the following formula :

$$S = 1000 - 300 \log \frac{d}{100},$$

where S represents the peripheral speed of the rolls in ft. per min., whilst d is the diameter of the pieces fed on to the rolls in inches.

In some cases the two rolls in a pair are driven at different speeds. This increases the crushing power and reduces the amount of slip. The difference in speed should not be excessive, or trouble will be caused by the rolls " bumping " and working irregularly. For low speeds one of the rolls may be driven by means of a belt and pulley, whilst the other is driven from the first roll by means of cog-wheels. For high speeds, however, this is impossible, and the rolls must be driven separately by means of belts, as geared rolls cannot be driven at very high speeds without their efficiency being much lower than when they are driven separately.

The output of crushing rolls depends on their size and shape, the size of the material supplied to the rolls, and the size to which the material is to be crushed. If the space between the rolls were continuously filled with crushed material, the output would be u. ft. per min., but as this condition is never fulfilled a more eet formula is

$$\text{Output in cu. ft. per min.} = AS\,(0\cdot6f - 0\cdot15),$$

where A is the area of the opening in square feet,
S is the speed of the rolls in feet per minute,

$$\text{and } f = \frac{\text{Space between rolls (in inches)}}{\text{Diameter of particles fed on to rolls (in inches)}}.$$

The power required for crushing rolls is rather great, about 3 h.p. being required for a pair of rolls 12 in. diameter and 10 in. wide. Rolls 21 in. in diameter require 9-12 h.p., whilst those 32 in. in diameter require about 15-18 h.p. to drive them.

Table LXIX. shows the output and power required for rolls crushing to grains about $\frac{1}{8}$ in. in diameter.

TABLE LXIX.—DATA FOR CRUSHING ROLLS

Diameter.	Length.	Revolutions per Minute.	Horse-power required.	Cwts. crushed per Hour.
in.	in.			
$10\frac{1}{2}$	$10\frac{1}{2}$	130	3	25
$12\frac{1}{2}$	$10\frac{1}{2}$	110	$4\frac{1}{2}$	45
16	$10\frac{1}{2}$	90	$6\frac{1}{2}$	65
21	$10\frac{1}{2}$	75	$9\frac{1}{2}$	100
27	11	45	$12\frac{1}{2}$	145
37	12	45	16	200

Crushing rolls are particularly useful for producing cubical pieces 2-$\frac{1}{4}$ in. in diameter. With soft materials they tend to give flaky pieces, but hard rocks and sands break into angular fragments. Rolls should not, as a rule, be used for finer crushing, as they are then wasteful in power, though, apart from this, they may be employed for reducing stone to a coarse powder.

On account of the great wear and tear on the surface of the rolls, it is necessary that they should be made of a very hard metal such as chilled iron or manganese steel. In most cases a rim of such material is fitted to a core of softer metal, so that, when worn, the rim may be renewed without the expense of obtaining an entirely new roll. In some crushing rolls supplied by Sutcliffe, Speakman & Co., Ltd., the rim is composed of several rings about 4 in. wide. As the centre of the rolls wears fastest, by using several rings instead of a single rim the worn part in the centre may be replaced by changing the position of the rings, so that

greater durability is obtained and the wear is kept uniform over the whole length of the rolls.

The uniformity of the surface of the rolls is specially important where the grinding is fine, as when the rolls are not properly cared for the size of the product is very irregular.

The rolls may be dressed, when required, by means of a grinding wheel. A special attachment should preferably be used, so that the rotating grinding wheel may be moved steadily across the surface of the roll without having to remove it from its bearings. This may be done by using a long screw carrying the frame which supports the grinding wheel, the transverse movement of the latter being accomplished by slowly turning the screw either by hand or by power. Fine emery or corundum wheels may be used with very satisfactory results.

When dressing a roll, it is rotated slowly and the grinding wheel is started at one end and is set so as to remove a thin " skin " at first. As the wheel reaches the centre of the roll it will not grind, as the wheel is too hollow at that part, but it recommences grinding as soon as it has passed across the hollow. After reaching the other end of the roll the reversing of the screw enables the grinding wheel to remove a further quantity from the roll. This is continued until all the hollows and depressions have been removed and a true cylinder is produced.

Edge-runner mills or pan mills consist of rolls of very large diameter but small width of crushing face, which crush the material contained on a pan or bed below the rolls. One roll or runner is sometimes used, but the machine is better balanced and a larger output is obtained if two rolls are employed. The horizontal shaft carrying the rolls on the shaft may be fixed and the pan or bed revolved, or the bed may be fixed and the rolls revolved. The latter (chaser mills) are the stronger and are largely used for crushing lumps of rock and reducing them to powder; mills with revolving pans are more economical in power and produce a better and more uniform powder if supplied with pieces of stone not exceeding 2-3 in. diameter.

Pan mills of this type are particularly useful for grinding moist materials, and as they have a very powerful mixing action they are extensively used in the sand-working industries. As they are chiefly used for fine grinding, they are more fully described later.

Precautions in Crushing.—Whichever form of machine is employed for the preliminary crushing, it should be sufficiently large to crush the largest pieces likely to be delivered to it. If many pieces have to be broken by hand the value of the machine is correspondingly reduced, yet many firms make the mistake of using too small a crusher for their purpose. Within reasonable limits, it is far cheaper to have an excessively large machine working well below its capacity but taking all the material fed into it than to have a smaller one working at full capacity but requiring 10 per cent of the material to be broken by hand because it is too large

to enter the machine. On the other hand, as the larger machines require much more power, it is not economical to use a machine which will deal with pieces far larger than are likely to be supplied to it. If the pieces too large to be crushed by the machine do not exceed 3 or 4 per cent of the whole output, it is usually cheaper to crush them by hand, or even to reject them, than to use a very large crusher. This is a matter which depends so much on local conditions that no general rules are of much value.

It is also wasteful to overload a crusher, as this causes clogging and results in loss of time and a low output. It should therefore be avoided as much as possible by the use of a sufficiently large machine. Overloading may often be avoided by the use of a screen or grid which separates all the material which is of the size of the crushed product and so does not need to go through the crusher. A suitable automatic feeding device is also invaluable, in some cases, for preventing overloading.

In order to avoid an excessive amount of dust from the crushers, it is advisable to employ chutes to deliver the raw material gradually into the crusher. These chutes may be perforated so as to act as screens and separate the small material, which can then by-pass the crusher.

If the dust from the crusher is very objectionable, it may be diminished by means of a series of fine water sprays or steam jets, which will damp the material slightly; an excess of water should, however, be avoided.

In the preliminary crushing the rock should be reduced to about the size of walnuts (*i.e.* ½-1 in. diameter), as pieces about this size may be dealt with satisfactorily in almost any kind of fine grinding mill without serious loss of power, whereas the same mill when supplied with pieces 2 in. or more in diameter may easily require 25-50 per cent more power. It is not, however, economical to reduce the whole of the rock to powder in the crushers, as the amount of power required would be excessive. The number of crushers and their sizes which will give the best results will depend on the size of the stones and on their nature, as hard stones will require more crushing and will therefore result in a lower output per machine than can be obtained with softer stone. In the sand-working and allied industries it is seldom economical to use a crusher which will accommodate pieces larger than 14 in. in their longest dimension, as such pieces usually form only a small proportion of the whole material and are preferably broken by hammers; where they are sufficiently numerous, however, larger crushers may be needed to deal with them. For economical crushing it is usually advisable to reduce from the largest size which the crusher will take down to about 4-in. cube in the first, from this size to 2-in. cube in the second crusher, and from 2 in. to ½ in. in the third crusher. Where only two crushers are employed, it is possible to reduce pieces 4-in. cube to about ½-1 in. at one operation, though when the output is sufficiently large to employ two crushers and a

screen to do the same work, the latter arrangement will be the more economical.

It is preferable to have the coarse crushing machines driven separately from the other machines. It is also very desirable to keep duplicate parts of the various fittings, as minor repairs are frequently needed.

One of the chief difficulties in the crushing of siliceous materials is the introduction of iron into the product. This cannot be entirely avoided, though by using special steel (such as manganese steel) for the grinding surfaces the amount of iron in the fine product may be reduced to a minimum. This is specially necessary in the case of sands used for glass-making, where a product containing less than 0·05 per cent of iron as ferric oxide is very desirable. The greater part of the metallic iron introduced in the process of crushing and grinding may be removed by a magnetic separator, unless it has become oxidised, when it is no longer attracted by a magnet.

The position of the crushers relative to the fine grinding plant is important. They should be so situated that the crushed material is delivered into a bin or on to a platform which acts as a temporary store from which an automatic feeding device may be arranged to supply the fine mill, or from which the crushed material may be shovelled into the fine mill as required.

Feeding Primary Crushers.—The output of a crusher is largely influenced by the manner in which it is supplied with material. In order that the supply may be as regular as possible, a charging platform or hopper is usually essential. Where the material is brought in wagons, it should be large enough to accommodate a reasonable number of wagons loaded with sand or rock, as well as the empty ones which accumulate before they ean be conveniently taken away. A small charging platform is a continual source of annoyance and risk, and it ought to be enlarged as soon as possible. The platform should be sufficiently above the crushers to enable the latter to be fed easily, and yet it should not be so high as to be inconvenient. The most suitable height for the platform is a few inches above the hopper of a gyratory crusher or the mouth of a jaw-crusher, so that the stones can slide into the machine down a hopper or chute. When a mixture of stones and sand is delivered to the crushers by means of a conveyor, a charging platform is less needed, provided the crusher has a sufficiently large hopper. In such a case the advantages derived from screening the material so that only the coarse powder goes to the crusher are so obvious that it is remarkable that so few firms use a screen for this purpose.

Automatic feeders for preliminary crushers must be of very solid construction on account of the large pieees of material delivered to them. Rotary base feeders, eonveyor belts, belt elevators, etc., described later for feeding fine grinding machines, may be adapted to feed preliminary crushers, but the wear and tear is very great.

For many purposes the most useful method of feeding crushers so as to secure a regular feed and not to put in any material which need not be crushed consists of an inclined grid or grizzly with a

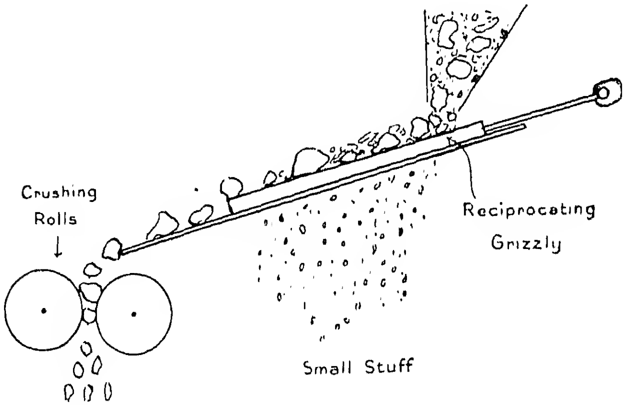
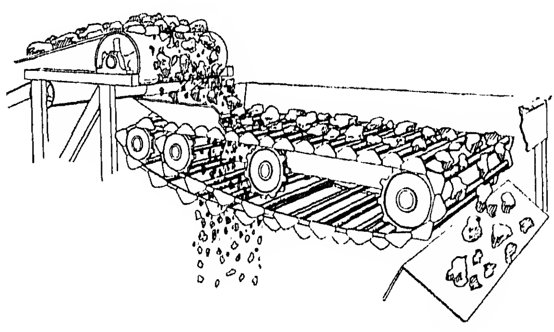


FIG. 70.—Reciprocating grizzly feeder.

reciprocating motion (Fig. 70). The material is tipped on to this, the small pieces passing through whilst the larger ones pass along and are discharged into the crusher in a steady stream. Another method consists of a conveyor belt composed of link-bars (Fig. 71) with convenient spaces between them. This belt allows the small material to pass through, but carries the larger stones to the

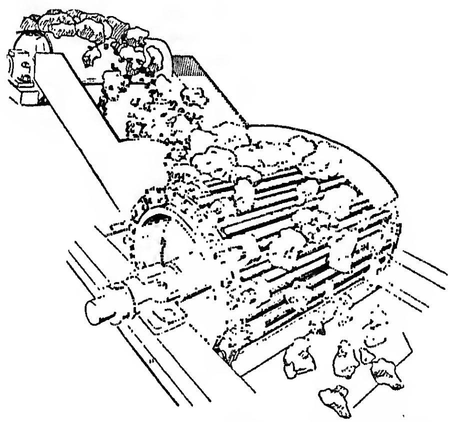


Sandycroft, Ltd., nr. Chester.

FIG. 71.—Ross belt feeder.

crusher. Being much longer, it has a much greater screening effect than a grid, but it requires cleaning frequently or the wear and tear on it will be very great. Fig. 72 shows a modification of this type of feeder in which a rotating cage is used instead of a link-belt.

A fourth feeding device (Fig. 73) consists of a number of discs mounted on a shaft so as to form a sort of roller supported in an



Sandycroft, Ltd., nr. Chester.

Fig. 72.—Ross feeder.

opening in the chute supplying the crushers. As the material falls down the chute, the large particles pass over the rotating discs,

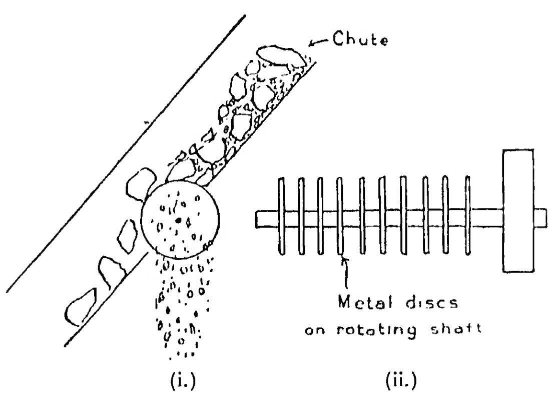


Fig. 73.—Disc feeder: (i.) side view and (ii.) front view.

whilst the smaller ones fall between them and downwards into a suitable receiver.

Grinding

The term " grinding " is used rather loosely, but is conveniently employed to mean the reduction of a material to powder as distinct

crushing," which is the process of reducing large lumps to pieces. Most material in pieces larger than $\frac{1}{4}$ in. would be ed," and material consisting of particles less than $\frac{1}{16}$ in. diameter would be termed "ground," but between these two sizes there is a considerable laxity in the use of the terms crushing and grinding. It is, however, more convenient to make the distinction between crushing and grinding one of process rather than product, so that the products from jaw- and gyratory-crushers, stamps and rolls, are regarded as having been "crushed," whilst the smaller-sized pieces and powders from other machines are regarded as having been "ground." In some cases, however, coarse crushing machines are used for fine grinding; thus, "bar" disintegrators may be used for crushing down to 25-50 mesh, and though they are not economical for producing fine powders, yet in grinding to a coarse mesh a considerable proportion of finer material will be produced. The final reduction of a silieeous material to the required size may be effected by either of two methods, namely, "dry grinding" and "wet grinding." The dry grinding method has the advantage of enabling the material to be passed over screens and separated into different sizes with greater ease than is the case with wet sand, which is more coherent than that in the dry state.

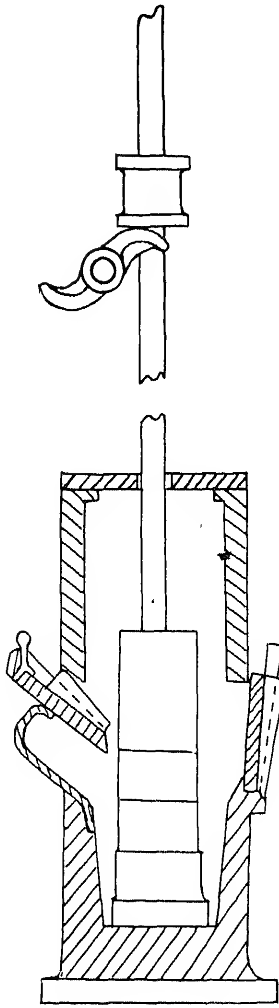


FIG. 74.—Stamp mill.

Dry Grinding may be effected by the use of stamps, ball mills, tube mills, pendulum mills, or edge-runner mills.

Stamps (Fig. 74) have been used for a very long time in reducing metalliferous sands to a finer state. One of the oldest types of stamps is the Cornish, which consists of a series of heavy weights which are lifted up by means of a rotating shaft fitted with a number of cams, and then allowed to fall.

The material escapes through a slit the height of which is adjustable so as to vary the time which the material remains under the

stamps. The stamps weigh about 2000 lb. each and rise usually about 7-20 in.; the number of blows is usually 16-32 per min.

The fineness of the product in dry stamps depends on their weight, the distance through which they fall, and the number of blows applied, *i.e.* on the time occupied in grinding.

In wet stamps, a stream of water is passed through the stamper, and this determines, to some extent, the fineness of the grinding.

The stamps are cylindrical in shape and are constructed of cast steel or tough white iron. The stamp is fixed to a cast-iron head, which in turn is fixed to a wrought-iron stem which carries a disc by means of which the cam on the driving shaft lifts the stamp and allows it to fall.

The stamps are usually arranged in a series of five, and are made so that they drop one after the other, the best order of dropping being 1, 4, 2, 5, 3, counting from left to right. Two sets of five stamps may be driven from one shaft, the engine being placed between the two.

In the Californian type, the stamps are made to revolve so as to ensure more even working. These stamps may weigh up to 1200 lb. and deliver about 80 blows per min. In a more recent stamper driven by pneumatic pressure, the stamps weigh 1250 lb. each and deliver 130 blows per min.; this stamp has an output of about 20 tons of sand per 24 hours.

On account of the weight of the stamps, the machines must be very strongly constructed. The bottom is usually built on a concrete foundation levelled off with a rich mixture of sand and cement; on this is placed a sheet of rubber $\frac{3}{8}$ in. thick, then a piece of wood 6 in. thick, and on this is placed the stamp box, which is made of cast iron with 1-in. drilled iron linings, the whole being bolted to the concrete foundation.

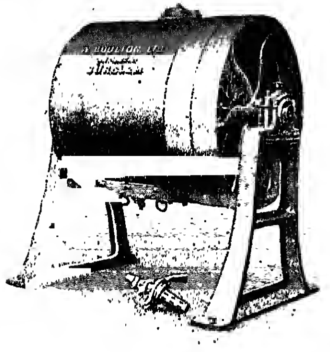
The power of a stamp is

$$\frac{w \times s \times l \times n}{60} \text{ ft.-lb. per min.,}$$

if w represents the weight of each stamp in lb., s represents the number of stamps, l represents the distance of drop in ft., and n equals the number of blows per min. It is usual to multiply the result of this calculation by $\frac{4}{3}$ so as to allow for friction; the result so obtained when divided by 33,000 gives the horse-power required to drive the stamps. Stamps give the best results when fed with material less than 2 in. in diameter.

Ball mills consist of a revolving cylinder, lined with specially hard plates of steel, flint, or porcelain, and containing a number of balls of iron, steel, porcelain, or flint, of various carefully determined sizes. The material to be ground is put in the cylinder, which is then closed and the mill is rotated, the impact of the balls upon the material reducing it gradually to the required size. Mills of this kind may be either intermittent in action, in which case they must be stopped, emptied, recharged, and started again at

intervals, or they may be made continuous by providing them with a suitable side-feed hopper and connecting an air-separator or screen to the ball mill, so that the whole forms one grinding unit, the coarse material from the separator or screen being returned to the mill and re-ground. The ball mills of a wholly enclosed type which work intermittently are commonly known as Alsing cylinders (Fig. 75); they are charged and run for a prearranged number of hours and are then discharged. Very fine powders can be obtained in this manner, but the process is expensive.



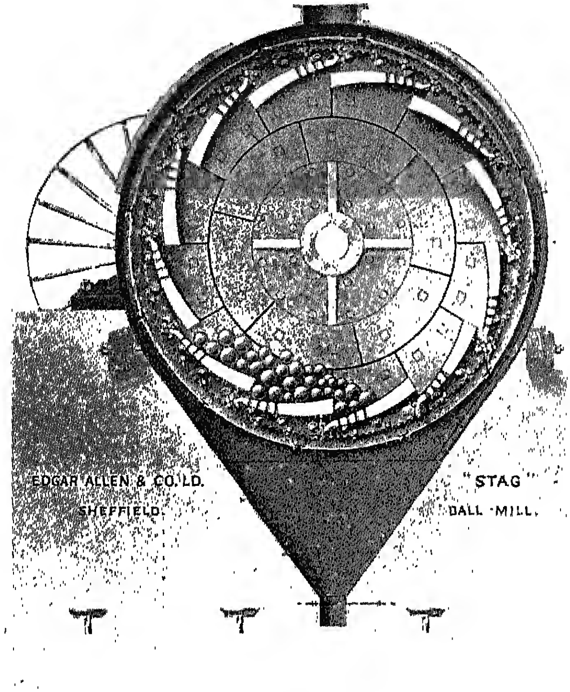
Wm. Boulton, Ltd., Burslem.

FIG. 75.—Alsing cylinder.

The continuous type of ball mill is provided with perforated plates of specially tough metals arranged so as to form a stepped grid. On rotating the mill, the balls fall and roll from step to step, crushing the material which is fed during their course. When the material is sufficiently reduced, it passes through the perforations between the plates and falls into a hopper below the revolving part of the mill. In some ball mills, such as those made by Messrs. Edgar Allen & Co., Ltd., Sheffield (Fig. 76), the fine material falls first on to a perforated steel plate, which separates the coarser grit, and then on to a wire gauze of finer mesh; the powder which passes through the gauze falls out of the mill and is conveyed away; the coarser material remaining in the mill is re-ground. The objection to ball mills with gauze is the wear and tear on the latter and the relatively small output of the mill. By removing all the material below $\frac{1}{8}$ in. diameter as soon as it is formed, and treating this outside the mill (as in an air-separator), all choking of the mill is prevented and the output is greatly increased. The tailings from the separator are automatically re-ground when they re-enter the mill.

A continuous ball mill made by Hardinge (Fig. 77) consists of an unsymmetrical double cone rotated by gearing and containing balls of varying diameter, from 5 in. to 2 in. or from $1\frac{1}{2}$ in. to $\frac{3}{4}$ in., according to the hardness of the material and the size of the product. The shape of the mill is such that the largest balls remain in the part of the mill which has the greatest diameter, whilst the others gradually distribute themselves along the cone in order of size, the smallest balls being found at the point of the cone. The part of the mill having the largest diameter has a much greater peripheral speed than the rest of the mill, so that the grinding effect is roughly proportional to the size of the particles; this effects a considerable

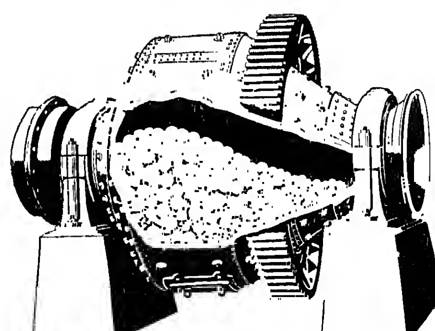
saving in power, whilst the conical shape of the mill, and the gradual



Edgar Allen & Co., Ltd., Sheffield.

FIG. 76.—Ball mill.

reduction in the peripheral speed as the ground particles pass along the mill, prevents the waste of power caused by the "cushioning" which occurs in many other mills.



Hardinge Co., London.

FIG. 77.—Hardinge ball mill.

The action of the mills is as follows: the stone, in small pieces not exceeding $\frac{3}{4}$ in. in diameter, is introduced into the mill so that it falls to the part of the greatest diameter, where it is ground by the largest balls travelling at the highest speed and falling through the greatest

e. As the pieces are reduced in size they move along l and come into contact with smaller balls travelling at speeds, until eventually the material reaches the point one at the farther end of the mill and is discharged. The ages of the Hardinge mill are its continuous operation, the high rate of grinding, and the small amount of power required, which is due to the progressive and rapid removal of the material, so that no energy is wasted by the presence of fine material amongst the coarser particles. Mills which are fed with $\frac{3}{4}$-in. or $\frac{1}{2}$-in. material may be used either wet or dry, and readily reduce any sandstone sufficiently fine to enable a large proportion of it to pass through a 200-mesh sieve.

An 8-ft. mill requires about 50 h.p. to reduce 5-10 tons of material per hour so that it will entirely pass a 48-mesh sieve, and 28·8 h.p. will reduce 1·7 tons per hour to so fine a powder that it will pass through a 300-mesh sieve.

The weight of the balls in proportion to the size of a ball mill is a very important factor in securing the maximum efficiency. Table LXX. shows the approximate weight of balls for mills of different sizes.

TABLE LXX.—SIZES OF BALLS IN CYLINDRICAL BALL MILLS

Diameter of drum in inches .	44	56	64	80	88	106
Width of drum in inches .	36	38	45	52	58	68
Weight of balls in cwt. . .	3·5	7	12	24	36	50

The weight of the balls should be kept as constant as possible by cleaning and weighing them about once a month and by making good any deficiency as often as is necessary.

The size of the balls used depends on the character of the material ground and of the product required. Hard materials and a coarse feed necessitate the use of larger balls, whilst for small and soft material small balls are required, but in all cases sufficient small balls should be used to fill the spaces between the larger ones. The Crossley Engineering Co. advise two hundred pebbles about 2 in. diameter in a 20-in. mill; and about forty pebbles of about $1\frac{1}{2}$ in. diameter in a 10-in. mill, the charge for a 20-in. mill being about 250 lb.; they also advise that the mills be filled to almost nine-tenths of their capacity.

The power required to drive ball mills of various sizes is shown in Table LXXI.

Ball mills should be supplied with small pieces of material, preferably not more than $\frac{1}{4}$ in. diameter, in order to secure the most rapid and economical grinding, but larger pieces are often supplied.

It is important that the mill should not be overloaded, as if

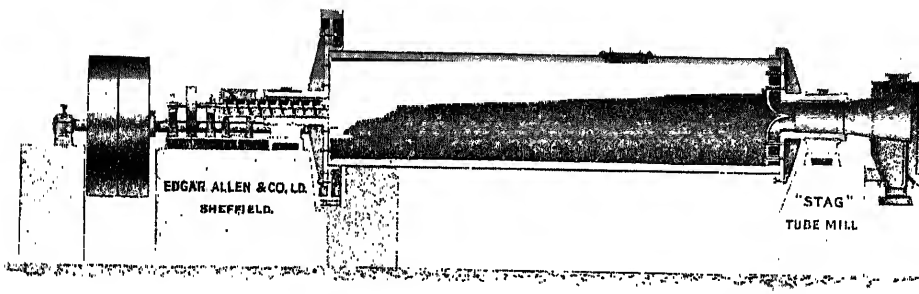
TABLE LXXI.—POWER REQUIRED FOR BALL MILLS

Length in feet	12	10	8	3
Diameter in feet	8	8	6	3
Horse-power	12	8	4	$1\frac{1}{2}$

too much material is supplied the time of grinding is disproportionately lengthened.

Ball mills are only suitable for use where rounded grains of sand are satisfactory; they do not produce angular grains, and so should not be used for purposes where angular grains are required.

Tube mills (Fig. 78) in many respects resemble ball mills, but



Edgar Allen & Co., Ltd., Sheffield.

FIG. 78.—Tube mill.

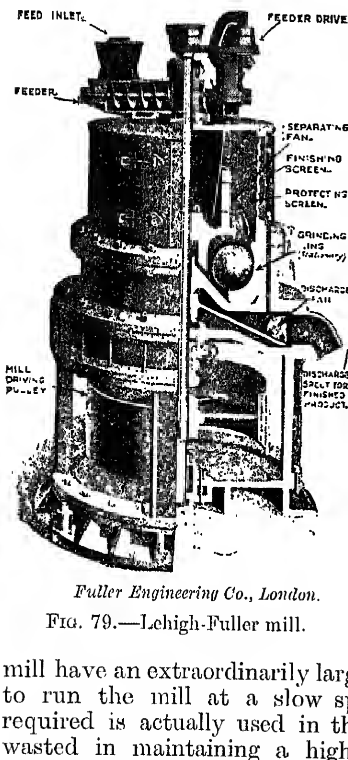
are longer and consequently much more suited for grinding large quantities of material to so extremely fine a powder that it is difficult to sieve it. It is found in practice that the uniformity of the product is so great that it is unnecessary to use sieves and no provision is made in the machine by which they can be used. In this respect a tube mill differs from a ball mill which delivers a product containing particles of various sizes. Like ball mills, tube mills also produce grains which are generally rounded in shape and not angular.

Tube mills are essentially "fine grinders" and work best when supplied with coarsely powdered material; for this reason, they are often used in conjunction with and in succession to ball mills.

The cylinder is slightly inclined and rotated at about 25-30 revs. per min. According to Davidson, the speed of rotation should be $\frac{200}{\sqrt{d}}$ revs. per min. where d is the internal diameter in inches. The coarse grit enters at one end through an automatic feed; it gradually passes by gravitation to the outlet at the other end, being pulverised

and reduced in its passage by the crushing action of the balls falling upon one another during the rotation of the cylinder. Flint balls or pebbles—being a natural product, comparatively inexpensive and of extraordinary hardness—are usually employed, but steel ones may be used where the presence of iron in the product is not objectionable.

When a tube mill is first started it is charged with pebbles or balls in prearranged proportions, but replacements are always made with the largest size, as the mill automatically produces the smaller pebbles in the course of its work. The weight of the balls or pebbles is usually about $1\frac{1}{4}$-2 times that of the material to be ground, or, according to Davidson, $\frac{1}{14}$ of the capacity of the mill in cubic feet.



Fuller Engineering Co., London.

FIG. 79.—Lehigh-Fuller mill.

The lining of the tube mill is composed either of cast-iron strips or of small specially prepared bricks of a nature somewhat resembling porcelain and laid in cement. The durability of a lining depends upon the character of the material to be ground, but a suitable lining should, with ordinary care, last at least a year. In many cases, linings serve eighteen to twenty-four months.

The output of a tube mill depends on the ultimate fineness to which it is required to reduce the material ground in it, and also upon the size of the pieces fed into it. By reducing the rate of feed, it is possible to produce a material of almost any degree of fineness.

The fact that the balls in a tube mill have an extraordinarily large grinding surface makes it possible to run the mill at a slow speed, so that almost all the power required is actually used in the grinding process itself and is not wasted in maintaining a high speed of rotation. On the other hand, the great weight of the balls in relation to the material to be ground makes tube mills costly to drive as compared with ball mills and sieves. In short, tube mills are expensive in first cost and in maintenance; they are moderately, yet not highly, efficient, and their chief recommendation is the certainty that the material is properly ground and requires no sifting or other treatment.

Lehigh-Fuller mills are a type of ball mill in which the centrifugal force of the balls is used instead of their weight. Such a mill (Fig. 79) consists essentially of a fixed cylinder containing

a hardened steel ring or race against which the material to be ground is fed. In the race is a number of hardened steel balls which are driven round in the race by means of a rotary casting, resembling a heavy rimless wheel with a ball lying loosely between each pair of spokes. Air currents caused by fans in the upper part of the machine lift up the smallest particles of material and throw them against sieves through which the finest particles pass, the remainder falling back into the race to be re-ground. The mill may be very conveniently fed by means of a screw conveyor (p. 382).

The Lehigh mill is especially valuable for the production of an impalpable powder (about 85 per cent passing through a 200-mesh sieve), when the quantity required would not justify the erection of a ball mill, but all centrifugal mills are extravagant in power in comparison with ball and tube mills.

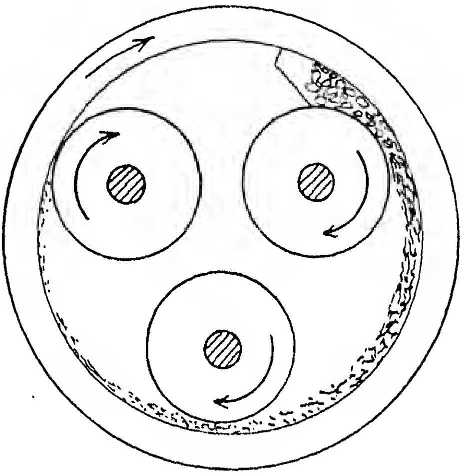
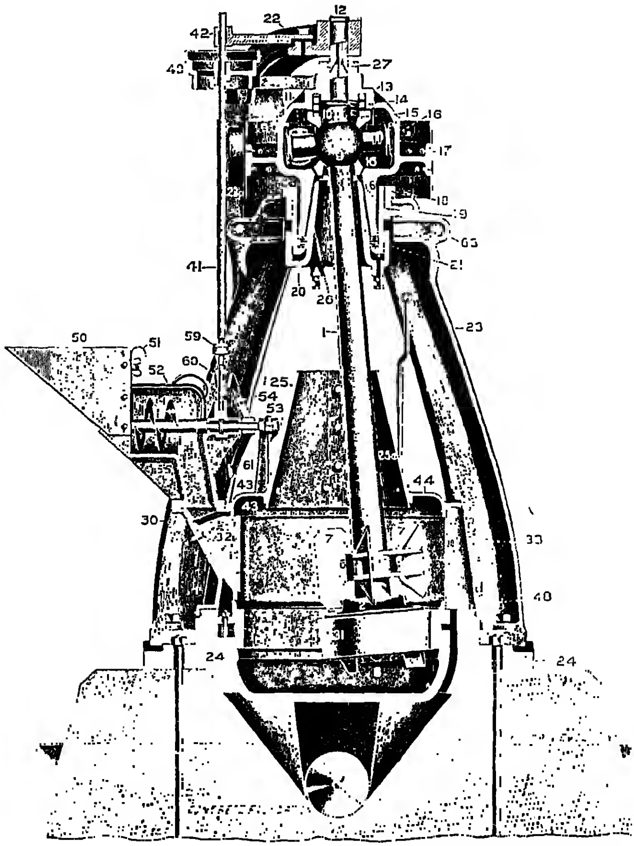


FIG. 80.—Roll mill.

Roll mills (Fig. 80) are also of the centrifugal type, but in them the ring against which the material is compressed during the grinding is arranged vertically instead of horizontally as in the Lehigh mill. Inside this ring are three rolls mounted on horizontal shafts: one of the rolls is positively driven; the other two rolls and the ring derive their motion by friction from the driven roll. The material to be ground enters the mill above one roller which acts chiefly as a feed roll, and the material is drawn by the revolving ring under this roll and on to the other rolls which complete the pulverisation. The mill takes about 25 h.p. to grind 1-3 tons of material per hour (depending on its hardness), if supplied with pieces up to 1 in. diameter, and the product will leave a residue of 8 per cent on a 100-mesh sieve. The same machine will produce 1 ton per hour of a material leaving a residue of only 7 per cent on a 200-mesh sieve.

Pendulum mills act in a similar manner to a mortar and pestle, though on a much larger scale. A typical mill of this kind is the Griffin mill (Fig. 81), in which the "pestle" consists of a shaft suspended vertically from a universal ball joint within the pulley from which the machine is driven, a small crushing roll being attached to the lower extremity of this shaft. As the shaft revolves,

the roll at its lower end swings radially outward and grinds any material between it and a ring or die which forms the "mortar." The pendulum shaft is mounted on trunnions which work in half boxes and slide up and down recesses in the pulley-head case, so that the crushing roll is free to swing in any direction within the



Bradley Pulverising Co., Ltd., London.

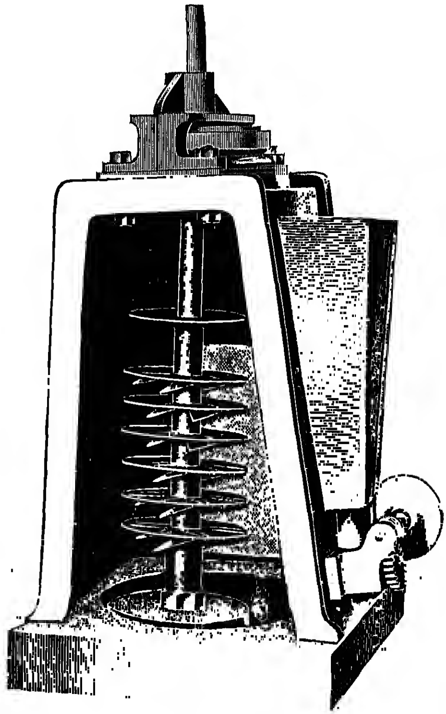
FIG. 81.—Pendulum mill.

casing. To the bottom of the roll is attached a series of ploughs or stirrers which violently stir the material in the pan which forms the bottom of the mill and throw it between the crushing roll and die. A fan attached to the shaft above the crushing roll keeps the ground particles in motion and drives them against a circular sieve or screen above the die. Those particles which are fine enough to pass through the sieve do so and are discharged from the machine

on to a conveyor ; the insufficiently ground particles fall back into the pan at the bottom of the mill, ready to be re-ground.

Griffin mills are driven at 150-200 revs. per min., at which speeds the makers claim that a pressure of 6000-8000 lb. is exercised against the die.

The " Gus " pendulum mill (Fig. 82), made by C. E. V. Hall,



C. E. V. Hall, Sheffield.

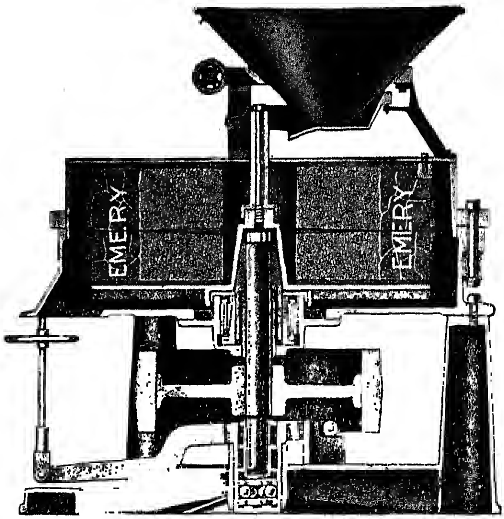
Fig. 82.—" Gus " mill.

Sheffield, is of similar design to the Griffin mill and is capable of grinding [illegible] pieces to an impalpable powder. A special feature [illegible] lies in the details of construction, which reduce the power required to much less than that needed by other pendulum mills having the same output.

Another modification of the ordinary type of pendulum mill is made by the Raymond Impact Pulveriser Co., of Chicago, U.S.A.,

in which from two to five pendulums are employed, each being suspended from a central casting which carries all the moving parts. The action of the mill is the same as in the Griffin type, the material being stirred up by scrapers and ground between the grinding ring and the pendulums.

Grindstones are sometimes employed for fine grinding. These machines usually consist of two circular grindstones running close together in either a vertical or horizontal position, so that the material is ground between their adjacent faces. Natural sandstone or chert carefully chiselled to the desired shape is usually employed, but artificial stones are being increasingly used. The



Sturtevant Engineering Co., Ltd., London.

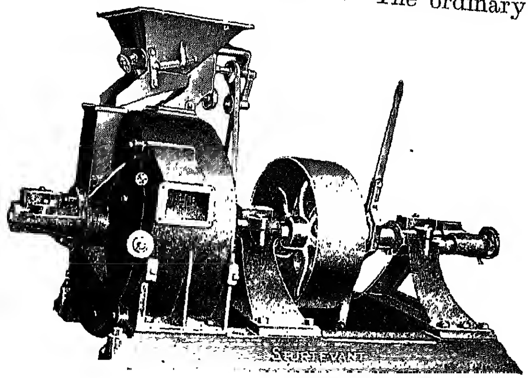
FIG. 83.—Horizontal grindstone or Burr mill.

stones may be of various sizes up to about 5 ft. diameter and are rotated at 120-180 revs. per min., the smaller stones being rotated the most rapidly. The power required is about 18 h.p. for an output of 1-3 tons per hour, depending on the hardness of the material to be ground.

Mills with a horizontal and a vertical stone respectively are shown in Figs. 83 and 84. Grindstones are chiefly used for reducing materials to an extremely fine powder ("flour"). At one time they were extensively employed, but they are now gradually being replaced by tube, ball, or pendulum mills.

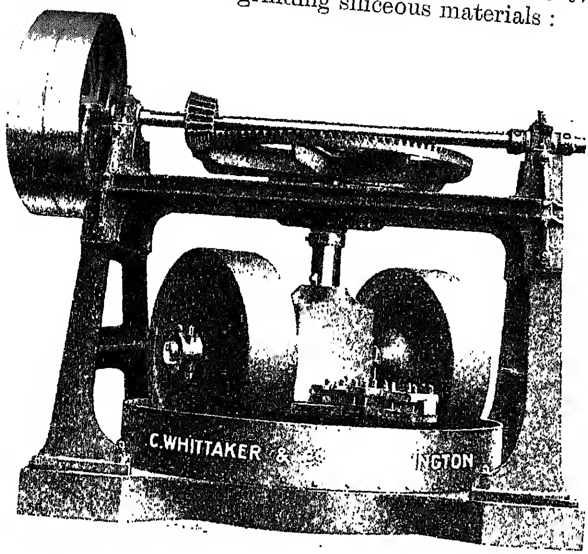
Edge-runner mills are largely employed for reducing siliceous materials used in the manufacture of silica bricks, sand-lime bricks, etc., where it is desired to produce angular particles without too large a proportion of dust. An edge-runner mill consists of a pair

of rollers mounted on a horizontal axle, which roll in a metal pan containing the material to be ground. The ordinary mortar mill



Sturtevant Engineering Co., Ltd., London.
FIG. 84.—Vertical grindstone mill.

is a well-known type of edge-runner mill. There are two types of edge-runner mill used for grinding siliceous materials :



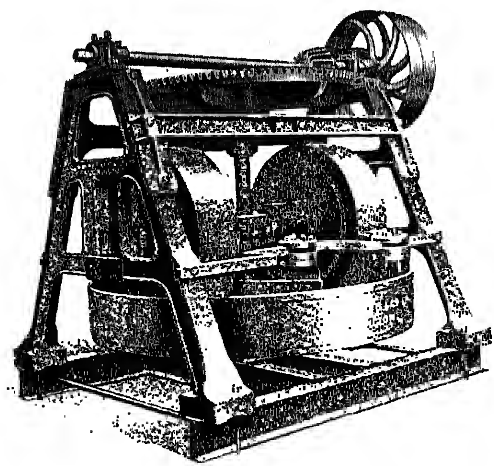
C. Whittaker & Co., Ltd., Accrington.
FIG. 85.—Chaser mill.

(i.) *Chaser mills*, in which the rollers follow each other in a fixed pan (Fig. 85).

(ii.) *Revolving pan mills*, in which the pan is rotated mechanically, the rollers merely turning on their axes as the result of the friction between them and the material to be ground (Fig. 86).

For reducing large pieces chaser mills are better on account of their great strength, but for pieces less than 3 in. diameter the revolving pans are usually preferable.

Chaser mills with fixed pans can be made stronger than mills of the revolving pan type, as the pan of the former can be placed on a solid foundation, and there is less liability of damaging it when the rollers are raised several inches by the introduction of large pieces of hard material. Edge-runner mills may be either over- or



C. Whittaker & Co., Ltd., Accrington.

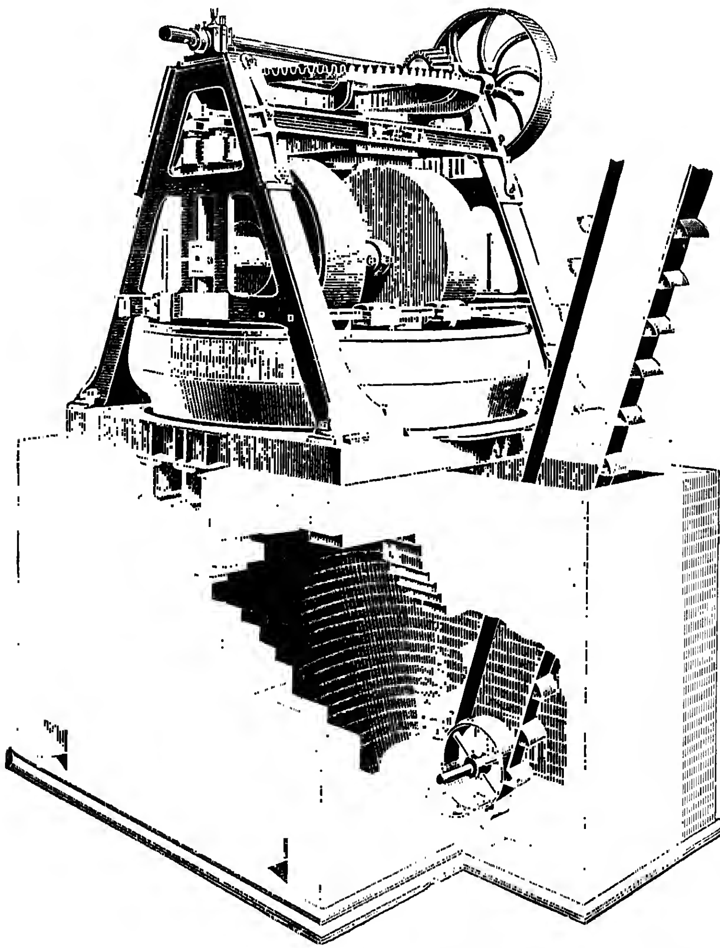
FIG. 86.—Revolving pan mill.

under-driven, the over-driven type being most generally used, as the gearing is more readily accessible, is less liable to be clogged by dust, and more space is available beneath the pan for the collection of the ground material (Fig. 87).

The gearing, whether the pan be under- or over-driven, should consist of a horizontal crown wheel of ample diameter and strength with well-cut teeth, driven by a pinion of corresponding strength and arranged to withstand many sudden and violent shocks. The drive should be through a belt to a countershaft, as it is not desirable to have several mills of this type all driven direct, though this is done in some works. The belt absorbs some of the shocks which would otherwise be transmitted to the driving shaft. Either a loose pulley or a simple form of clutch should be provided, so that the machine can be stopped rapidly when required.

The pulleys should be properly selected for the work they are

to do. Too narrow a pulley is a serious mistake, as it causes more wear than one which is of ample width for the purpose. As the power transmissible by a belt or pulley is proportional to its width,



C. Whittaker & Co., Ltd., Accrington.

FIG. 87.—Open-base pan mill.

it is always wise to err on the side of one which is too large, rather than too small. Owing to the dusty nature of the material, rubber and canvas or similar belts are preferable to those made of leather. The belt should be kept properly dressed.

In mills with revolving pans, the footstep bearing on which the

ıpright shaft carrying the pan is supported should as it has a much heavier load than is commonly .d be made in two parts so as to facilitate examina-.placement when required, and should be so designed that .ot be affected by the shocks to which the pan is subjected. ıld be lubricated with grease or oil of good quality, which should be supplied automatically as far as possible, though the necessity for occasional inspection should not be overlooked, as footstep bearings are costly to repair.

The pan is lined with chilled metal or steel plates, or chert slabs mounted so as to form an easily renewable bed. The metal plates may conveniently be arranged in two concentric circles, the inner one, preferably made of tough manganese steel, being the grinding bed on which the material is subjected to the pressure of the runners, whilst the outer one (which for cheapness may be made of chilled metal, as it is subject to less wear) serves for mixing the material and repassing it under the runners. The rim of the pan may be made in one or more pieces as desired ; it should be vertical rather than sloping, though some grinders prefer the latter.

The pan may be solid or it may be perforated with holes or slots. A perforated pan is preferable for dry material, as it is continuous in action ; the material when sufficiently finely ground falling through the perforated bottom of the pan and escaping from the machine. In the solid pan, on the contrary, the machine must be stopped at intervals and emptied, recharged, and started again ; this involves a waste of time which should, if possible, be avoided. Dry materials should never be ground in a solid pan, as much of the material is lost in the form of dust and there is a great waste of power. When the material is not too hard, the rollers may be raised about $\frac{1}{4}$ in. above the pan, as this reduces the amount of dust produced. Instead of the whole of the pan being perforated, the parts immediately below the rollers may be solid, whilst the rest of the bottom of the pan may be perforated. Scrapers may be arranged which carry the ground material on to the perforated part of the pan and return that portion which will not pass through holes to the grinding bed for further treatment. In some cases, the sides of the pan may also be perforated, though this is seldom necessary. The shape of the perforations varies, slots being used in some mills, whilst in others circular holes are employed. The latter are preferable, as they prevent large flakes from passing out of the mill. If slots are used, their length should usually be at right angles to the track of the rollers, unless the presence of flaky pieces is not considered objectionable, when the output of the mill may be increased by having the length of the slots in the direction of the travel of the rollers. Both perforations and slots wear somewhat rapidly (unless the pan is made of exceptionally hard metal) and should be renewed before the apertures become unduly large.

The size of the perforations varies with the purposes for which the ground material is to be used, but it is inadvisable to use holes

smaller than $\frac{1}{8}$ in. diameter, as they are liable to be easily clogged and require frequent cleaning. If a pan mill is used to grind a material to powder, the material from the mill should be screened and the coarser material returned to the mill to be re-ground. Although all the material thus returned is capable of passing through the perforations in the mill, it will, if delivered to a solid part of the pan, be reduced to much smaller particles before being discharged through the perforations. It is by no means unusual to employ screens of 24-mesh, in conjunction with $\frac{1}{8}$-in. perforations in the pan, with completely satisfactory results.

The holes in the pan should taper so as to be larger on the under surface of the pan than on the upper one; this largely prevents the holes from being clogged.

Edge-runner mills used for dry grinding must be very strongly built; the runners should be as heavy as possible, and are best if constructed of iron and fitted with renewable rims or tyres of steel or special hardened metal. The employment of these removable tyres has many advantages, one of the most important being the cheapness with which the working surface of the runner can be kept reasonably level.

Some firms prefer the runners to be made of stone, and where it is necessary to avoid the use of iron this material is excellent. For most purposes, however, it is better to fix on them a renewable type of manganese steel or chilled iron, as unprotected stone wears away rapidly. An excellent arrangement when transport charges are heavy is to make a skeleton runner of iron and to fill it with concrete when the runners have reached their destination.

The runners must be so constructed as to allow of their vertical movement through a distance of at least 6 in., so that in the event of a large mass, too hard to be immediately crushed, getting into the mill, the runners may pass over it. If this cannot be done, an excessive strain is placed on the driving gear and an accident may result. One excellent method applicable to mills with revolving pans is to suspend each roller by means of two chains, but a more usual one is to provide slots in the standards carrying the ends of the runner axles.

From the point of view of durability, the best pan mill is the one which has the maximum output for the smallest pan-area; hence it is necessary that the scrapers should be fixed very carefully so as to work with the greatest efficiency. They should be arranged so as to mix the material thoroughly and to pass it as often and as completely as possible beneath the runners. Each scraper should be capable of separate adjustment, both horizontally, so as to ensure that it moves the material in the desired direction, and vertically, so that it may be lowered as the metal wears away. Some firms on the Continent use hanging scrapers which rest on the material by their own weight and can move vertically without being adjusted. If the scrapers are fixed to arms pivoted on a shaft, at the back of the machine, the front of the pan may

be left more free and accessible than is usually the case ; this greatly facilitates the emptying of the machine when this has to be done by hand. There are, however, objections to self-adjusting scrapers, and those which must be adjusted by hand are preferable ; they remove material which would otherwise adhere to the pan, and so ensure a better mixture than is obtained with loose scrapers. The smaller the perforations the closer should the scrapers work to the bed.

The output of edge-runner mills depends on the number of revolutions of the pan or rollers, the number of scrapers, and the speed with which the powdered material is removed from the mill. The quality of the product depends on the breadth of the runners, the form and number of the scrapers (which regulate the number of times the material is passed under the runners before it is removed), and the time taken in grinding.

To secure the greatest output, edge-runner mills must not be overloaded, but should be fed in a regular manner, preferably by one of the automatic feeders described on p. 382, with material which is not in unduly large pieces. No maximum can be applied in all cases, but as a general rule no pieces should be larger than 3 in. diameter, and if the largest size is only 1 in. so much the better. It is cheaper to reduce large pieces to 1 in. in diameter in a stone-crusher than in a pan mill, so that a crusher is economical as a preliminary breaker for this purpose.

It is very useful, in many cases, to attach an apparatus consisting of a lever, one end of which is placed so that when a runner is raised too high above the level of the bed it will automatically move the lever and ring a bell, thus indicating that the machine is being overfed, and that the supply of material should be reduced.

Edge-runner mills are chiefly used for reducing sandstone, silica rock, ganister, etc., to a fine powder, in the manufacture of bricks, etc. They are also used for the preparation of material for sand-lime bricks and in the reduction of metalliferous sands for further treatment.

The chief disadvantages of dry grinding silica and other sharp-grained materials in edge-runner mills and other open mills, is the danger to which the operators are exposed on account of the dust which rises from the machines and causes *silicosis*, which, in some cases, is fatal. This may be avoided by enclosing the mills and using fans to collect the dust, but this is sometimes troublesome and difficult.

Wet grinding may be carried out by means of stamps (p. 364), ball, or tube mills (p. 365), grindstones (p. 374), or edge-runner mills, which are used in a similar manner as in dry grinding, except that water is present as well as the material to be ground. The chief differences in the appliances used in wet grinding and dry grinding respectively are :

Wet Stamps.—Instead of passing the material through a slit, it is carried by a stream of water on to suitably placed screens.

Ball mills for wet grinding are of similar design to those used for dry grinding, but where fine material is required the mills must usually work intermittently (as Alsing cylinders, which are charged and run until the machine has sufficiently ground the material; the mills are then emptied and recharged). For coarser grinding, wet mills with continuous action may be used.

Tube mills are more adaptable for wet grinding than ball mills, the construction being practically the same as for dry grinding. The mill is filled up to about its centre line with balls or flints, and the slurry is admitted at one end and discharged at the other, the exit being fitted with a sieve to prevent the escape of the balls.

Grindstones for wet grinding are similar in construction to dry grindstones, though only horizontal stones are used; it is found that in wet grinding only the lower stone should revolve, as this secures a greater output than when the upper stone is rotated. In wet grinding, the stones are driven at about half the speed used for dry stones, so that less power is necessary. Artificial stones are preferable to natural ones, as they wear longer and are in every way more satisfactory.

Edge-runner mills or *Pan mills* for wet grinding must work intermittently, as they cannot satisfactorily be worked continuously. They usually have a solid pan and runners 5 ft.-5 ft. 6 in. in diameter, 16-18 in. wide, and weighing about half a ton. The pan should revolve and the rollers be loose. The mills may be under- or over-driven, as desired. The usual charge for an edge-runner mill is about 600-1200 lb., which is treated for 20-30 mins., and then withdrawn. No material which is more than 1 in. diameter should be supplied to the mill. Such a mill, charged each time with 750-900 lb. of silica, will deliver regularly about 1 ton per hour, the mill being emptied and filled three times per hour and requiring 25-30 h.p. according to the hardness of the material.

A pan mill is usually emptied by hand assisted by some simple device. Long-handled shovels mounted on a universal joint are largely used, and are effective, but rather risky, and therefore undesirable. No wholly satisfactory method of emptying the revolving pans without stopping the mill has yet been devised, though several ingenious devices are sufficiently satisfactory for some purposes. Their chief disadvantage is that continuous working introduces the continuous feeding and the continuous withdrawal of material from the pan, so that the product is never so well ground as in machines which work intermittently with batches of material supplied at regular intervals.

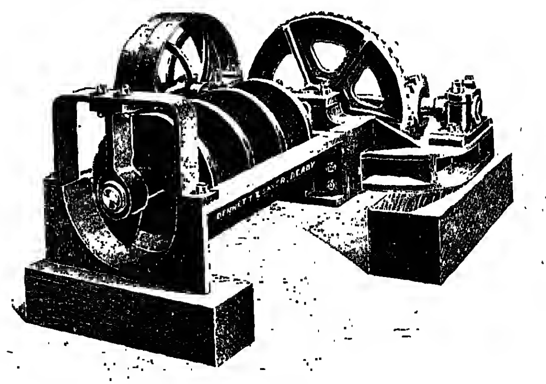
When a stationary type of pan mill is employed, it may be emptied by opening a sliding door which covers a hole in the pan.

All edge-runner mills should be charged uniformly, and care should be taken not to overload them or to run them with too small a charge; consequently, it is desirable to use a measuring device, or to weigh the charges; where a sufficient number of mills is used, a poidometer (p. 334) may be employed.

The duration of grinding should depend on the nature of the material being ground. About three charges per hour are attained most siliceous rocks which have previously been reduced in eliminary crusher.

Levigating mills—used for the wet grinding of flint in the pottery industry—consist of a circular vat 4-6 ft. wide, the bottom of which is paved with hard (chert) blocks. In the centre is a vertical shaft provided with stout horizontal arms which, when rotated, move large irregular blocks of hard stone (chert) over the paved bottom of the vat and so reduce any material placed in it to powder.

Wet grinding has the advantages of avoiding the production of dust and of producing a finer product, though the angularity of the grains is usually destroyed.



Bennett & Sayer, Ltd., Derby.

FIG. 88.—Screw feeder.

Automatic Feeders for Grinding Mills.—The efficiency of any grinding mill depends very largely on the rate at which the material is fed into it. The ideal method is to supply the material to the mill in a continuous stream at exactly the same rate as that at which it is being discharged in the ground state; this is not usually possible, so that the most satisfactory method of feeding the mill is that which most nearly approximates to a continuous feed.

Hand-feeding would be ideal with a proper attendant, but in practice it is seldom really satisfactory, as the man either supplies too much material at once, thereby overloading and choking the mill, or he is over-cautious and does not secure the maximum output which the mill is capable of supplying. An automatic feed, when properly adjusted, overcomes both these drawbacks, as by its means a perfectly uniform supply of material to the mill is ensured. Automatic feeders are of four chief types :

A *screw conveyor* (Fig. 88), in which the material is tipped into

a horizontal trough containing a slow-moving screw or worm, and carried forward at a rate which depends on the size and speed of rotation of the screw and on the length of screw-thread acting on the material to be moved. By varying this length by altering the position of the screw on the shafts, the output can be controlled very accurately.

A *scraper conveyor*, consisting of a vertical drum with an independent revolving base-plate (Fig. 89) carrying a scraper, which, as the base-plate rotates, pushes a regular stream of material through an opening in the side of the drum, or between it and the base, into the mill. The amount of material delivered may be varied by altering the size of the aperture, the speed of the base-plate, or the size or position of the scraper.

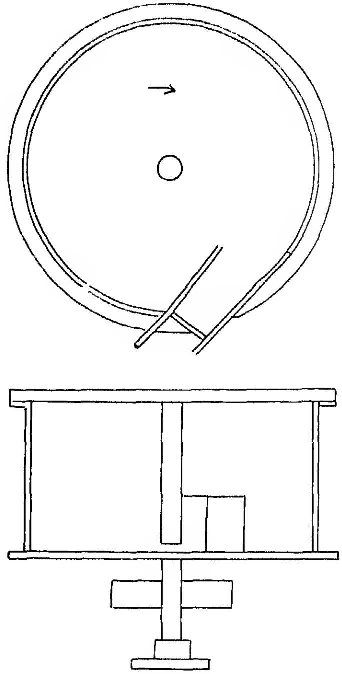


FIG. 89.—Revolving base-plate feeder.

A *conveyor belt*, above which is mounted a barrier or block, adjusted so as to allow a suitable amount of material to pass beneath it, any surplus being held back and eventually carried forward by a less heavily loaded portion of the belt. This type of feeder is very useful where several mills are to be fed from one source, but the wear and tear on the belt is rather high.

An *endless belt fitted with buckets* or other containers which are automatically filled and discharged at intervals. This type of feeder is merely a modification of a bucket-elevator (p. 339).

The essential characteristics of a good automatic feeder are: (*a*) strength, (*b*) simplicity of design and construction, (*c*) low driving power, (*d*) resistance to wear and tear, and (*e*) unlimited capacity to receive and deliver the material in a perfectly regular manner to the mill. The first two types of feeder described above are very regular in their action, but are rather expensive in power. The other two are also satisfactory, though their use is limited, and the last-mentioned is not really continuous, but intermittent, though the intervals are very small. Each method is better than hand-feeding, because it is usually more regular than the latter. The saving in power effected by the use of mechanical feeders is very considerable, and if the feeders are carefully selected they soon repay the initial expenditure involved.

CHAPTER IX

PURIFICATION OF SANDS AND SAND-ROCKS

The purification of sand and sand-bearing rocks may be effected in several different ways, according to the nature of the material and the amount of purification necessary. The principal methods employed are :

(i.) Hand-picking.
(ii.) Washing.
(iii.) Concentration by
   (*a*) Water.
   (*b*) Floatation.
   (*c*) Air.
   (*d*) Magnetic separation.
   (*e*) Electrostatic separation.
(iv.) Chemical action.
(v.) Calcination or burning.

HAND-PICKING

Hand-picking is only employed where the impurities are in the form of relatively large pieces which can conveniently be picked out by hand. Coarsely ground stone may be hand-picked to remove portions which are too badly contaminated by iron compounds, etc. Gravel or pebbles may sometimes be removed from sands by hand-picking, but these materials may often be separated equally satisfactorily and more economically by means of screens. Except in special cases, hand-picking is not applicable to sandy materials, and their purification is usually effected more economically by mechanical or other methods.

WASHING

Washing consists in applying water to the material in such a manner as either to remove undesirable constituents or to remove the sand and leave the impurities behind. Thus, a mixture of

sand and clay is washed in such a manner that the clay is removed by the water, but when a mixture of sand or gravel is washed the water carries away the sand and leaves the gravel behind. Sometimes the washing is so arranged as to effect a separation into particles of low and high specific gravities; this is particularly the case in dealing with placer sands and other deposits containing valuable minerals or ores. This treatment is termed "Concentration" (see p. 413).

In washing, the clay and other small particles are separated from the remainder in accordance with (*a*) their weight, (*b*) their size. In the former method the larger particles settle out of *suspension* whilst the clay, etc., is carried off by the wash-water, and in the latter method the larger particles are retained by *screens*, through which the water and smaller particles escape.

In both these methods, the water not only removes the clay and silt, but also a considerable proportion of any carbonaceous matter

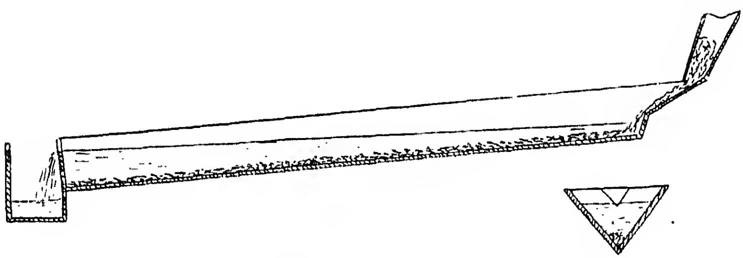


FIG. 90.—Trough washer.

present; some ferruginous matter may also be removed, though the separation of iron films on grains of sand is much more difficult. Thus, the Triassic and Permian sands cannot be completely purified by washing, as the grains are covered with a thin adherent film of haematite which is very difficult to remove. Grains coated with limonite are more readily cleaned by washing, though this treatment will not remove the whole of the iron present as limonite.

Washing by Suspension.—Various methods of applying the water in order that it may carry off the small particles of clay and other impurities, are in use. One of the simplest but by no means the most economical, is by means of the *trough washer*, which consists in putting the sand in a long trough having a V-shaped cross-section (Fig. 90), through which a constant stream of water is kept running; the sand is stirred up by hand, using rods, spades, or other stirring devices so that each grain of sand is brought into intimate contact with the water, and the adherent particles of dust and clay are removed and washed away by the stream of water, leaving the clean sand behind. It is impossible with this arrangement to use the water efficiently, so that a very large quantity of water is required; the time occupied in washing is also much

longer than when more efficient mechanical methods are employed. The method is, therefore, confined to cleaning small quantities of sand where a more elaborate device would not be profitable; apart from its cost, the method is quite satisfactory. It may be made more effective by having a series of troughs one below another, as this increases the chance of the sand being thoroughly cleaned without using more water.

Flat-bottomed troughs termed *sluices* are often used for washing large quantities of sand, especially those containing precious metals. Such sluices are about 12 ft. long, from 1½-2 ft. wide, and 1 ft. deep, the floor sloping 2-21 in. in its length of 12 ft.; in some cases, the floor of the trough forms a series of steps about 4 ft. apart. Sluices are used in exactly the same manner as V-shaped trough washers.

A still greater improvement can be obtained by using a mechanical agitating device to ensure the thorough admixture of

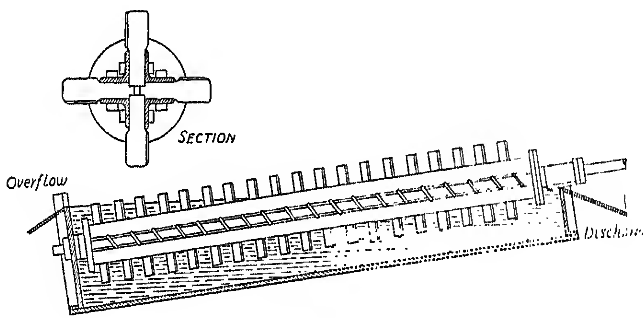


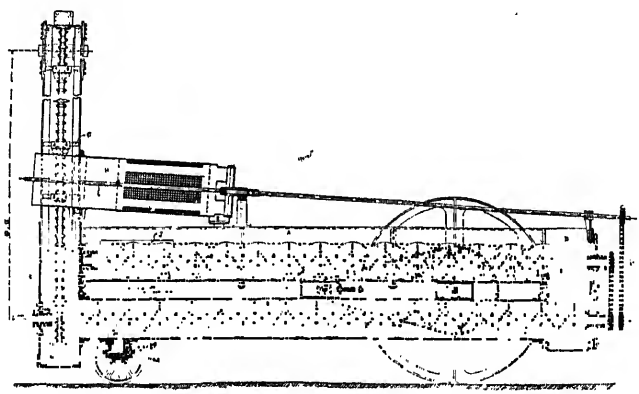
FIG. 91.—Log washer.

the sand and water. Thus, one of the simplest of such troughs is the *log washer* (Fig. 91) which is frequently used for washing metalliferous sands, the simplest form consisting of an inclined wooden trough, lined with wrought or cast-iron plates and fitted with a shaft carrying paddles arranged at an angle so as to mix and convey the material to be treated from the lower end to the upper end of the trough. The shaft revolves at about 12 revs. per min., and discharges the washed sand at the top end of the trough, the water travelling in the opposite direction and carrying with it the dirt, clay, etc., removed from the sand.

Another form of trough which is sometimes used for removing clay and dirt from metalliferous sands consists of what is known as a *mud-wheel*, namely, a paddle-wheel 5 or 6 ft. in diameter, which revolves in a trough containing the sand and water. The paddles lift up the sand and allow it to fall again into the water, thus putting the clay and dirt in suspension so that they escape when the water is run off. In the Greenaway washer (Fig. 92) manufactured by Hardy & Padmore, Ltd., Worcester, the sand is fed on to an inclined rotary screen through which it is washed by jets of water,

any gravel being separated by the screens. The sand and water fall into a long trough provided with a rotating shaft carrying a large number of blades which churn up the sand and water and gradually transport the sand to the farther end of the trough, whilst the water flows in the opposite direction. On reaching the end of the trough the sand falls through a tank, up which a current of water is rising, into a second mixer similar to the first, through which the sand is conveyed in a direction contrary to that of the water flowing through.

Finally, the thoroughly washed sand is discharged into a tank of clean water from which it is raised by a bucket elevator with perforated buckets which allow most of the water to escape. The elevator discharges the sand on to the ground or into wagons or



Hardy & Padmore, Ltd., Worcester.

FIG. 92.—Greenaway washer.

bins as required. The length of the mixing troughs and the fact that the water and sand travel in opposite directions ensure the sand being thoroughly washed, without much waste of water and with a minimum amount of attention.

The efficiency of all these types of sand washer depends on (*a*) the extent to which the clay, etc., is separated from the sand and is suspended in the wash-water; (*b*) the speed of the current, which determines the size of the particles which will be carried away and, therefore, controls the amount of impurity left in the sand and the amount of sand carried away and lost; and (*c*) the sizes of the smallest particles of sand which it is desired to retain, as this limits the speed at which the water can be allowed to flow through the trough.

The combined effect of (*b*) and (*c*) causes the grains of sand to travel downward and at an angle which depends on the two forces concerned. Thus, a grain of sand which will just pass through a 20-mesh sieve will settle in still water at the rate of nearly 4 in.

per sec., but in a trough through which a current of water is flowing at the rate of 12 ft. per sec., the grain will travel longitudinally for some distance before it settles. Eddies in the stream and variations in the stirring also affect the deposition of the particles.

The amount of agitation of the crude sand and water necessary depends on the ease with which the grains of sand are separated from each other. If much clay is present, a very thorough agitation is required, whilst a clean sand composed of almost pure quartz will enter into suspension almost immediately.

The rate of flow of the water should be controlled by valves or other suitable means so as to carry off the clay and "dirt" without losing too much sand. The best rate must usually be found by experience, and particularly by collecting the liquid running away from the end of the trough, allowing it to settle and then noting

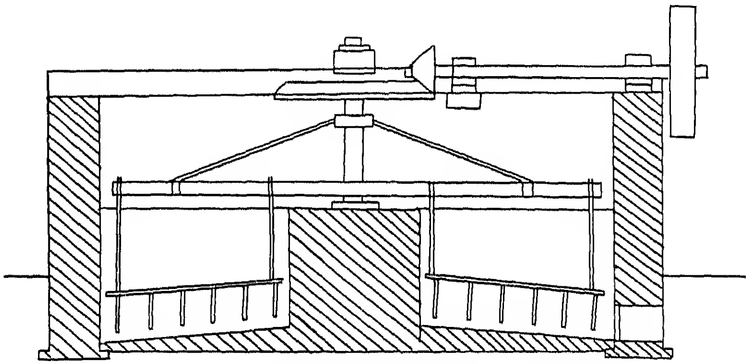


FIG. 93.—Wash-mill.

how much sand is present in it. This is dealt with more fully under Elutriators (p. 391).

Baffles or riffles are sometimes used in washing troughs to aid in the retention of the larger particles.

Among other arrangements for agitating the sand and water, the most satisfactory are wash-mills, drum, tube and conical washers with internal agitators.

In some cases the agitator is separate from the washer proper; the latter then usually takes the form of either an elutriator or of a series of settling tanks.

A **Wash-mill** (Fig. 93) consists of a circular tank or annular ring 6-15 ft. in diameter and 2-6 ft. deep. In the centre is a vertical shaft which is rotated either by a horse, engine, or motor. Attached to the vertical shaft are several horizontal arms carrying harrows which trail in the sand and water in the mill, and stir them up, and put both sand and clay, etc., in suspension. After a sufficient amount of stirring, the rotation of the arms is stopped and the contents of the mill are allowed to remain motionless, thus

separating the clayey matter from the sand. The water and clay are then run off through an opening in the side of the mill and afterwards the clean sand is removed, either by digging or by means of a small bucket elevator. Attempts to work wash-mills of this type in a continuous manner (by removing the sand continuously with an elevator at the same rate as fresh sand is admitted, the stream of water also being continuous) have not proved completely satisfactory, though they are sufficiently so in some localities.

An intermittent wash-mill, when horse-driven, is capable of washing 16-28 tons of sand per day, but an engine- or motor-driven wash-mill may treat 120 cu. yds. of sand per day of 24 hours.

The chief drawbacks of a wash-mill are the very large quantities of water involved, the intermittent nature of the process, and the ease with which a careless or indifferent workman may deliver improperly washed material. They are, therefore, used to only a limited extent.

Drum washers may be regarded as covered trough washers; being "closed" they can be worked at a greater speed and inclined more steeply than an open trough washer. When horizontal, they consist of a pipe or cylinder containing a shaft bearing a series of blades which churn up the sand and water and produce a good mixture. The blades are so inclined that they also propel the sand to one end of the washer, whilst the water is under such a pressure that it travels in the opposite direction. This counter-current action ensures the cleanest water coming into contact with the cleanest sand, thereby economising water and ensuring as thorough a washing as the machine can produce.

If the drum is inclined, the shaft and blades must usually be replaced by a continuous or Archimedean screw; in that case, the sand is admitted at the lower end of the drum by means of a hopper, and water is admitted at the upper end and travels downward through the washer. The rotary motion of the screw conveyor causes the material to pass up the inclined drum and fall out of the end at the top. In passing up the drum, it is agitated by the motion of the screw, and the adherent dirt is washed out and carried away by the water which overflows at the lower end of the drum. A machine of this kind is capable of washing 20-50 or more cu. yds. of sand per day.

The efficiency of such a washer depends on the speed of the water and on the extent to which the particles of sand, etc., are separated as they travel through the drum. The agitating and separating power of a series of blades in a horizontal drum is far greater than that of a complete screw, so that the inclined drum is usually less efficient unless made of very great length. For many sands the inclined drum, extended so as to form a pipe, possesses ample agitating and suspending power and is, in every way, satisfactory, provided the sand and water travel in opposite directions. When they both travel in the same direction, a longer pipe is necessary to ensure a perfectly clean product.

A particularly successful washer of this type is the *Freygang Separator* (Fig. 94), which consists of an inclined tube *a*, with a vertical branch *e*, an overflow a^1 with waste pipe *g*, and a worm-conveyor *c*, rotated by gearing driven by the pulley *b*. The material to be washed is agitated with water in a separate mixer or blunger and is fed into the funnel e^1 along with a supply of clean water from the pipe *f*. The mixture passes to the inclined tube *a*, and rising through it is gradually separated so that the fine particles of clay, etc., are carried away through *g*, whilst the washed sand is collected in the tank *d*. The object of extending the tube *a* well above the outlet a^1 is to ensure the sand being drained before it is discharged from the machine.

The fineness of the separated particles and the grading can be regulated by altering the inclination of the tube *a*, the speed

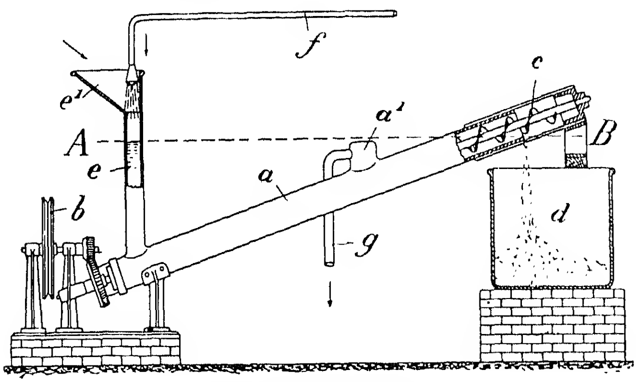


Fig. 94.—Freygang washer.

of rotation of the worm *c*, and the quantity of water supplied by *f*. When several grades of sand are required, a corresponding number of separators may be worked in series. Similarly, where several washings are necessary the solid matter from one machine may be discharged into another, and if necessary a series of machines may be used so as to secure a sufficiently pure product.

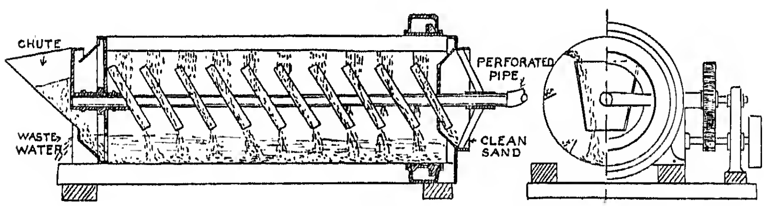
Machines of the Freygang type have the following advantages :

(1) Definite mechanical control, giving definite results in the separation or grading of the sand.
(2) Great saving in the amount of water used.
(3) Great range of grading, when required.
(4) Low cost of installation.
(5) Very little power required. An output of 20 tons per hour requires 12 h.p. and 40 tons (8960 gallons) of water. Most of the water can be used repeatedly. Small machines with an output of 1 ton per hour require about 1 h.p.

(6) The machine is specially useful for concentrating metal-bearing sands.

Instead of the drum being stationary and fitted with a revolving shaft and blades, it is sometimes advantageous to use a horizontal rotating drum fitted with internal baffles. In the Blackett coal washer the baffles are in the form of a screw or worm, so that the heavy particles caught by the baffles travel down the worm-shaped channel until they escape at one end of the drum, whilst the fine particles are carried to the other by the water and thus separated.

In another case, the baffles are arranged so as to lift the sand and deliver it on to fixed blades on a stationary shaft. The Telsmith washer (Fig. 95) is of this type; its action is clearly shown by the illustration. Machines of the rotary driven type do not break up balls of clay and sand so readily as fixed drums with



Smith Engineering Works, Milwaukee, Wis., U.S.A.

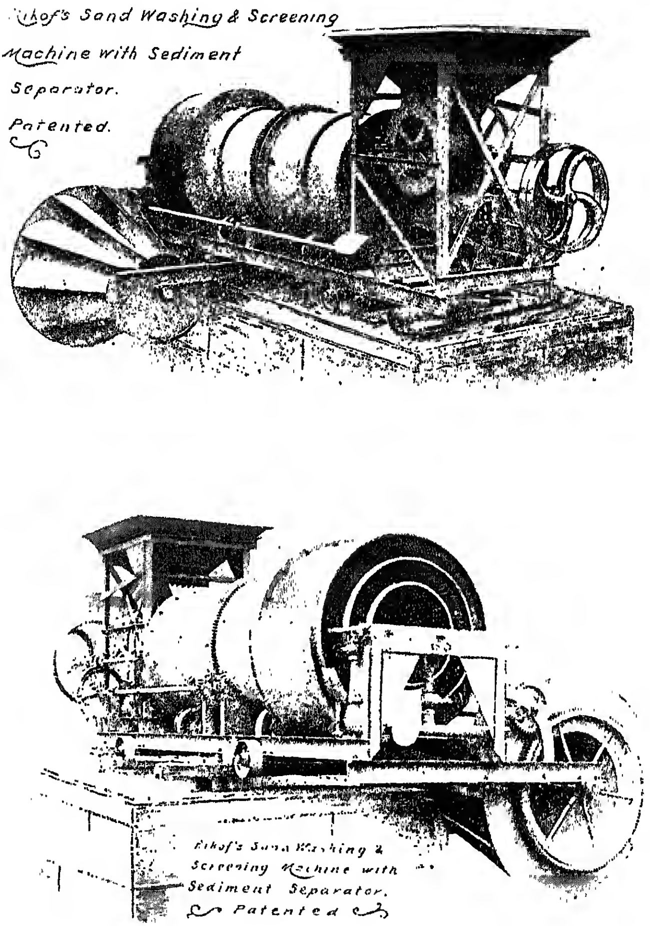
FIG. 95.—Telsmith washer.

rotating blades, but for sands which are easily washed they are quite satisfactory.

In Rikof's washer (Fig. 96) the slightly inclined drum is divided into several compartments through which the water and sand pass in opposite directions, the sand being discharged at the lower end of the drum on to cylindrical screens of suitable fineness arranged concentrically, the largest holed sieves being innermost and the finest on the outside of the series. The sand on the screens is also subjected to a further cleaning by means of jets of water playing on the screens. The slurry may, if desired, be carried off to a drying apparatus where it is de-watered and dried (p. 404).

Elutriators are appliances for separating small solid particles by means of a current of water flowing at such a rate as to carry away the smaller particles or those of lower specific gravity, whilst the larger or denser particles remain behind. Elutriators are all based on this separating power possessed by a current of water flowing at a predetermined rate (p. 252), and their efficiency depends on (i.) the accurate regulation of the rate at which the water flows, (ii.) the absence of disturbing currents, and (iii.) the supply of the materials in a state of suspension, each solid particle being definitely separated from the others. Most of the washers

lescribed depend upon this principle, but elutriators n other washers in having no internal mechanism. implest form of elutriator is that described on p. 252,



Perfect Concrete Mixer Co., Broxbourne.

Fig. 96.—Rikof's sand washer.

but it is too small for use with large quantities of sand. For use on a large scale, it is not sufficient merely to construct a large vessel of the shape shown in Fig. 18, as eddies and other disturbing factors would render it of little value; moreover, it is important

to be able to remove the washed sand easily at regular intervals without interfering with the work of the elutriator. These difficulties have been overcome without sacrificing any of the essential principles in the separator patented by J. M. Draper of the Rhondda Engineering Co., Ltd., Bridgend.

The Draper washer consists of an iron column at the lower end of which is a screw conveyor. Water is admitted through a pipe 5 (Fig. 97), near the upper part of the apparatus, and fills it, gradually overflowing through the shoot 3. A balancing column of water may be attached to pipe 7 so as to keep the pressure of the water constant in the apparatus. The material to be treated enters the apparatus through the hopper 2, and falls through the funnel 18. Here it is subjected to a powerful washing action by the movement of the water, whilst the heavier particles gradually settle downwards and are carried away by the conveyor. The nature of the falling material may be seen through the windows 22 and samples may be drawn through the plug 23. The valve 25 slowly rotates, and in so doing shuts off the connection between the water column and the conveyor sufficiently to enable a steady separation to be effected, whilst at the same time it enables the accumulated sand, etc., to pass away. Apart from this valve and the conveyor, the apparatus has no moving parts and requires no attendance when at work.

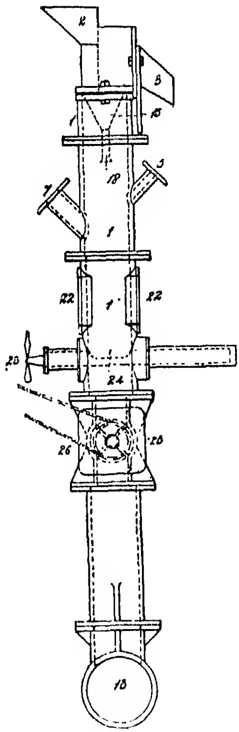


FIG. 97.—Draper washer.

When supplied with a mixture of sand and water in which the solid particles are completely separated (as by agitation in a beater-mill or blunger), the Draper washer is remarkably efficient. It depends solely on the rate at which the water flows through the apparatus and thus reduces the control to ensuring an ample supply of water at a constant head. It does not require the water to be under great pressure, and when once adjusted it requires no further attention. It can be regulated to separate particles within very narrow limits of size or specific gravity, or to remove all particles less than, say, 200-mesh without losing any appreciable proportion of the larger particles. It takes up less space than almost any other kind of washer, and it has the advantage that it can be arranged to give any desired output, whether small or large, by varying the size of the apparatus. It does not require any power to drive it, as the sand-emptying valve can be turned by hand if desired, though a

mechanical rotating device is preferable and its cost may be neglected if a pump is required to supply the separator with water.

To be effective, the Draper washer must be of a considerable height—seldom less than 10 ft.—and whilst this is not serious, it is interesting to observe that most inventors of elutriating washers have avoided tall appliances wherever possible, though usually without very adequate reasons. They have also endeavoured to design washers of large diameter instead of using a larger number of small diameter. This is unfortunate, as the disturbing factors in an elutriator are far less serious in an apparatus of small diameter than in a larger one.

For these reasons, instead of employing a tube or pipe as in the types already mentioned, cones are often used as in Figs. 98 and 99. Such washers are really elutriators, the sand falling to the bottom whilst the clay and dirt are carried away by the water passing upward through the cone.

Where materials coarser than 200-mesh are to be washed, some of the impurities which are neither so light as to float away nor heavy enough to sink, accumulate on the sides of the cone. In time these accumulated particles slide down the cone, spoiling the washed sand therein and necessitating a stoppage of the process whilst the cone is being cleaned. This may be avoided, to some extent, by supplying the slurry from one side instead of down the centre, or a block may be placed in the centre of the apparatus, as in the Delano washer, so as to send the water down the part of the cone where the deposit is likely to form, and thus prevent its deposition. The defect is, however, largely due to the use of an inverted cone and so cannot be wholly avoided with washers of this shape.

The object of making a washer of inverted conical form is to create a rapid flow of water at the point where it first comes in contact with the sand, so as to separate the solid particles and put them in a state of suspension. As the water rises in the washer, the conical shape of the latter reduces the rate of flow so that an increasing amount of settlement of the larger or denser particles should occur, though the rate of flow should still be sufficiently great to carry off the clay and " dirt."

In the simplest form of cone elutriator the crude sand is fed into the upper part of the cone at such a distance below the overflow as to prevent undue disturbance of the latter. The particles of sand, etc., pass downwards and are gradually separated, the smaller and lighter particles being carried upward by the current, whilst the larger or denser particles sink to the bottom and are withdrawn through a valve. If the crude material contain large pieces of cemented material (*e.g.* pellets or " balls " of sand cemented by plastic clay) they will not be broken up, as the action of the washer is too gentle, but will sink down along with the particles of sand. Hence, this type of washer is useless for such a material.

Numerous patents have been granted for minor variations in this type of washer, and they need not be described in detail.

The valves which control the discharge of the sand from conical washers are often troublesome, and many ingenious devices have been used to overcome this difficulty. Thus in a conical washer (Fig. 98) manufactured by the Allis-Chalmers Manufacturing Co., Milwaukee, Wisconsin, an inverted conical sieve is placed in the lower part of the washer. The apertures in this sieve are too small to permit sand to pass through them, though they readily admit water under pressure from the valve in the base of the washer. This arrangement efficiently prevents most of the sand from entering the valve.

The cone washer manufactured by the Allen Cone Co., El Paso,

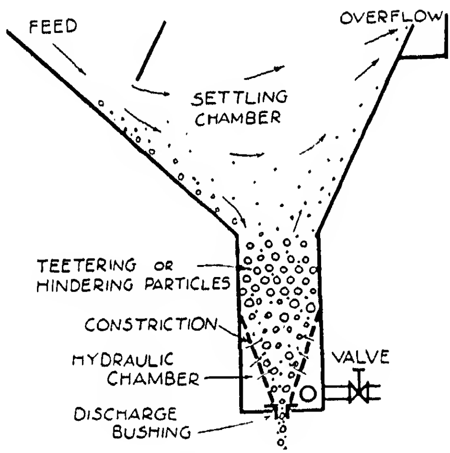
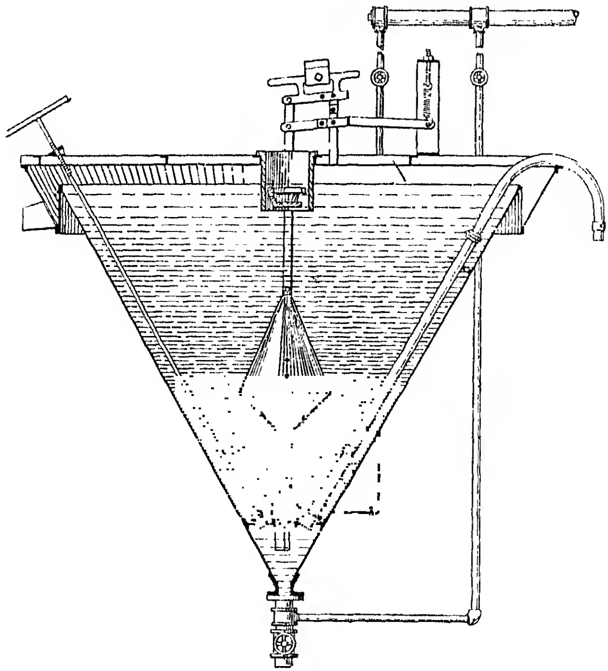


FIG. 98.—Allis-Chalmers cone washer.

Texas, U.S.A. (Fig. 99), is provided in the centre with a float which is just in a state of equilibrium when the washer is filled with clear water. When the washer contains a large amount of material in suspension the float rises, and, in so doing, it opens a valve in the bottom of the apparatus and causes some of the sand to flow out, thus reducing the density of the liquid and reclosing the valve. In this way the accumulation of sand is effectually prevented, as the float rises immediately a few grains of sand sink to the bottom of the cone, and, being very sensitive, it acts with great accuracy. The sand and water passing through the valve enter a chamber below, where it comes into contact with a stream of water and is drawn off by a siphon, this being preferred as it causes less disturbance than a valve in the bottom of the washer. Such a device is more suitable for washing very fine sands than for coarser ones. In America, it has been used successfully for removing clay from fine

phosphate sands of 200-mesh grade, which are washed completely clean.

The Dorr classifier (Fig. 100) consists of a very shallow cone, the material in which is agitated slightly by means of slowly rotating rakes. These do not interfere with the general washing process, yet they prevent the formation of deposits on the sides of the cone and drive the coarse material through the discharge opening into a water chamber, from which it is removed by means of a ladder



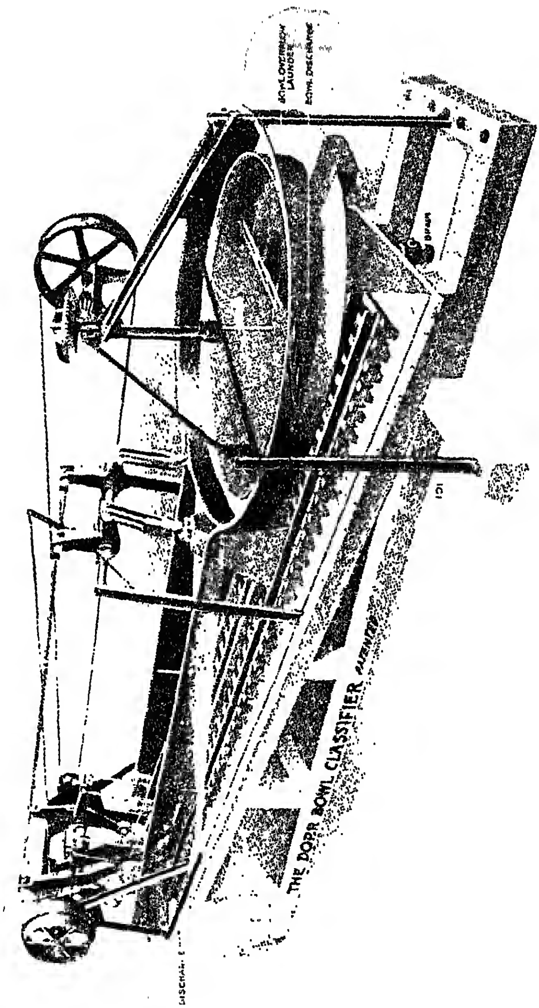
Allen Cone Co., El Paso, Texas, U.S.A.

FIG. 99.—Allen cone washer.

conveyor consisting of a series of blades on a long rod, the whole having a to-and-fro motion. On the forward stroke, the scrapers are close to the bottom of the inclined trough containing the sand and they draw the material up the machine. On the return stroke the scrapers are lifted clear of the material and are then lowered so as to draw a fresh lot of material forward. During the return stroke the water and finest material tend to flow down the incline and enable a well-drained sand to be discharged from the machine.

Washers of this kind can effectively clean a sand containing 25-50 per cent of clay at an extremely low cost, only 1 to 5 h.p. being required for outputs up to 75 tons per hour. Dorr classifiers

are very useful for washing moderately fine sands (such as those used for glass manufacture) which require to be specially free from impurities.



Dorr Co., London.

Fig. 100.—Dorr bowl classifier.

The Korting washer is a type of multiple cone washer in which the sand is passed through a series of hoppers. The sand is placed in the first hopper, where it is stirred up with water under a head of 30-40 ft. The water, with the clay and other impurities, flows

lip of the hopper to waste, but the sand is lifted up a vertical tube (by the pressure of water through an and is carried to the next hopper for further washing. .ocess is repeated as often as necessary. There are no ...ically moving parts, and the apparatus requires no attention .ier than to feed it and remove the washed sand from the catch tank in which it accumulates.

Another general form of cone washer and classifier (of which several patterns exist) which has long been employed in the treatment of metalliferous sands is the *Spitzkasten* (Fig. 101), which consists of a box in the form of an inverted pyramid with its oblique sides at an angle of 50° and made of wood or sheet iron. The slurry is introduced at one side and escapes at the other, a baffle being placed between to prevent surface currents. In some patterns the slurry is introduced through a tube down the centre

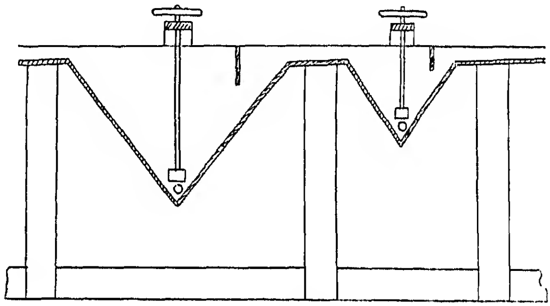


FIG. 101.—Spitzkasten.

of the box, extending to within 2-3 ft. of the top of the pyramid. A secondary supply of water ascends from the bottom of the cone and aids in carrying away the fine grains of sand, etc., whilst the heavier particles sink to the bottom and are periodically removed. Several such [illegible] may be used in series in order to separate parti[illegible] sizes. When several Spitzkasten are used in series, the first box should be 2 ft. wide, if 10 cu. ft. of the mixture of material and water (known as "pulp") or 1-2 cwts. of solid matter are to be treated per minute. The boxes in the series may suitably increase in geometrical progression with a factor of 1·5 ; thus if the first box is 8 ft. in length, the second may be 12 ft., the third 20 ft., the fourth 30 ft., and so on.

A *Spitzlutte* classifier (Fig. 102) consists of two inverted triangular prisms, one inside the other, the space between them being adjustable. This apparatus is used in the same way as the Spitzkasten, the sediment being withdrawn at the apex of the outer chamber. In some cases, secondary water is supplied to the base of the apparatus so as to give an upward current which ensures the best possible classification. Both these washers may be used

for concentrating and classifying sands as well as for washing them.

Washing with Screens.—Some sands can be effectively and cheaply washed by discharging them on to one or more screens in a thin stream, and applying a sufficiently powerful stream of water to carry the clay and small particles through the screens, whilst the larger particles travel along the screens and are eventually discharged.

It is sometimes sufficient to mix the sand and water in a hopper or some form of preliminary mixer, the contents of which are then passed over fine screens which retain the sand whilst the water and

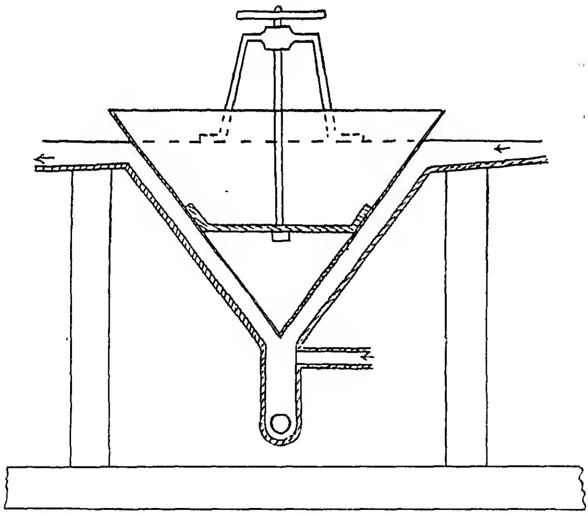


FIG. 102.—Spitzlutte.

dirt flow away. The drawback to such an arrangement lies in the tendency of the sand to act as a filter and retain some of the impurities suspended in the water. This objection is much less when the impure sand and water is passed in succession through a number of screens, fresh water being supplied to each screen if necessary, and finally after separating all particles which can be removed by the screens, the water containing the finest particles in suspension is taken to a sand settler. A number of inclined conical screens arranged in series for this purpose as shown in Fig. 103 is largely used in America.

In another form of washer, rotary cylindrical screens are arranged so as to be partially submerged in water, so that the fine material which passes with the water through the sieve is collected in the tank containing the screen; the coarser sand remains on the sieve and the dirt and clay are carried off by water to an overflow

pipe. In this way very thorough washing is secured and a large output maintained.

In some works a series of flat vibrating screens are arranged

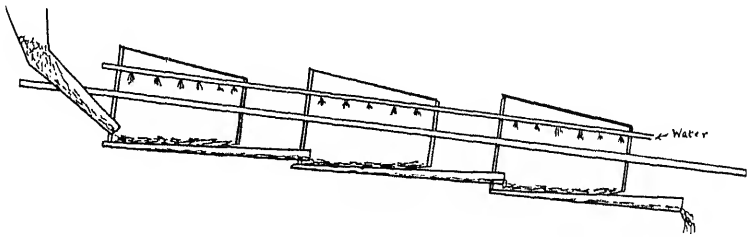


FIG. 103.—Conical washing screens.

one above another, as in Fig. 104. The sand is supplied to the uppermost screen and is graded and washed by jets of water which drive it, according to the sizes of the particles, through each screen in turn. The objection to this arrangement is that the sand acts

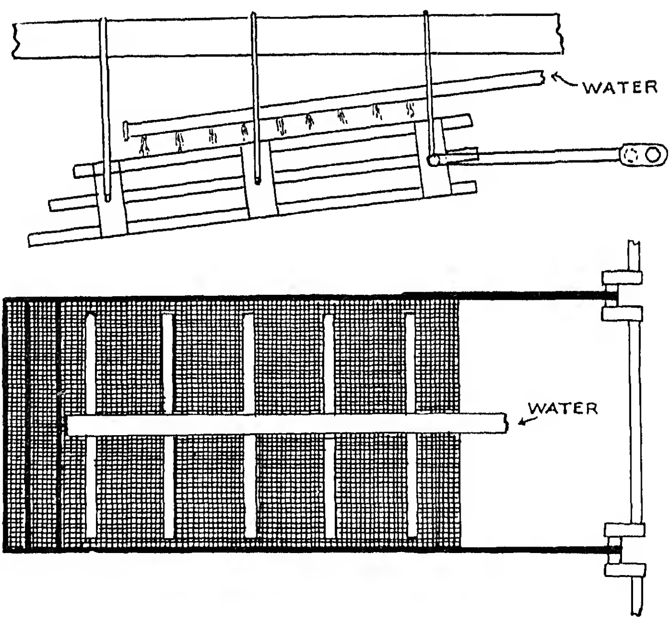


FIG. 104.—Washing screens.

as a filter and retains some of the dirt, which would be separated if the sand were fully suspended in water and the dirt removed by flowing water without the use of screens.

Removal of Water from Sands

After washing, sands usually contain a considerable proportion of water which must be removed before they can be used. Various methods are employed to effect this de-watering; they may be subdivided into (*a*) sedimentation; (*b*) filtration; (*c*) centrifuging; and (*d*) evaporation or drying.

Sedimentation is very commonly used, and is applied in various ways. The simplest method is to run the sand and water into large settling pits. After a time, the sand falls to the bottom and the clear water is allowed to run off through an overflow pipe, or through a series of openings in the side of the pit. This method has long been used in the purification of china clay and in other industries, the chief disadvantage being that it is very slow and the space occupied is considerable. Moreover, the removal of the sand by hand labour is costly, so that more rapid methods which include mechanical devices are preferred.

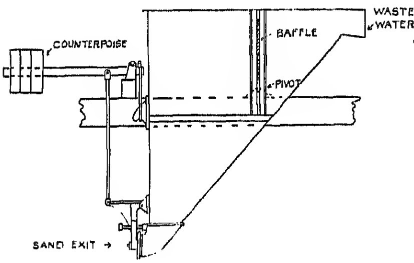
The settling pits may be rectangular or circular with vertical sides, but it is usually more convenient to use inverted cones, the sand being discharged through a valve at the apex of the cone. The mixture of sand and water is supplied to the cone either just over the rim or through a vertical pipe in the centre of the cone. Both these arrangements have the disadvantage of forming "banks" on the sides of the cone unless special precautions are taken (see Cone Washers, p. 394), as by providing a combination of washer and separator as in the cone washers previously described. In some cases the wet sand is tipped into a conical hopper and is allowed to settle. The sand is then drawn off through a valve in the bottom of the cone, whilst the water remains behind or is run off through an overflow.

In the Boylan separator the cone is suspended from the arm of a balance, the other arm being provided with a counterpoise, so that when a sufficient weight of material enters the cone its equilibrium is displaced, the cone sinks, and thereby opens a valve at its base and so discharges some of the sand. The cone then rises, and the process is repeated as often as may be necessary. In the conical sand separator made by the Link Belt Co., Philadelphia, U.S.A. (Fig. 105), the cone is suspended from a system of levers attached to a valve in the apex of the cone. The mixture of sand and water flows into the top of the cone, the sand falling to the bottom and the water passing away by the overflow pipe. The weight of the sand gradually causes the cone to sink, and doing so opens the valve, thus releasing some of the sand, which falls into a bin, restoring the balance and closing the valve. This device is therefore entirely automatic, provided the sand is sufficiently free from stones, etc., not to choke the valve. A cone 6 ft. diameter at the top will deal with 5 tons or 1000 gallons of a mixture of sand and water per minute.

A counterpoise separator of a different shape is made by the

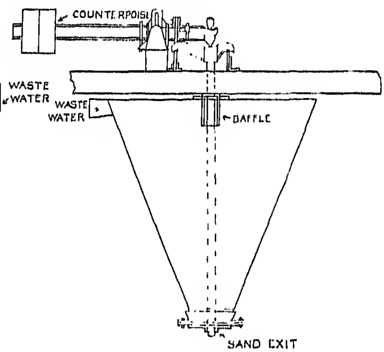
Smith Engineering Works, Milwaukee, U.S.A. In this machine (Fig. 106) the hopper and lever are both carried on knife-edge bearings to ensure sensitive action, and as the sand-laden tank moves in one direction the valve plate at the bottom moves in the opposite direction, thus giving an ample discharge area and a reliable closure on the return movement and avoiding the tendency for the valve to remain open too long, which is so serious a fault with many counterpoised sand-separators.

The advantage of a separator of conical or similar shape is that it enables a relatively small discharge valve to be used, the sloping sides of the cone automatically directing all the sand to the outlet. The disadvantage of such an arrangement is the difficulty frequently experienced in closing the valve promptly, especially when attempting to produce a dry sand. For this reason, many of the American



Smith Engineering Works, Milwaukee, Wis., U.S.A.

FIG. 106.—Smith de-watering cone.



Link Belt Co., Chicago, U.S.A.

FIG. 105.—Link-belt de-watering cone.

separators do not attempt to deliver a dry sand but only one containing as little water as will avoid valve-difficulties. Such devices are really rapid drainers, and leave the sand in a saturated condition.

A conical sand separator must be very deep to be effective, as a shallow one would allow too much water to pass with the sand.

Where a conical separator is not used, the chief means employed for withdrawing the sand from settling pits are: (i.) drag-belts; (ii.) bucket elevators; (iii.) ladder conveyors; (iv.) Archimedean screws; and (v.) rotary drainers.

Drag-belts (Fig. 107) consist of an endless belt or chain provided with scrapers which draw the sand up an incline at the side of the settling pit, but allow the greater part of the water to flow back into the pit.

Bucket elevators (p. 339) are sometimes used to raise the wet sand from a settling pit. The buckets are usually perforated so as to permit most of the water to drain back into the pit. They are only useful where the colour of the sand is of no importance,

as the metal of which they are made usually rusts and so contaminates the sand.

Ladder conveyors consist of a series of scrapers mounted on a

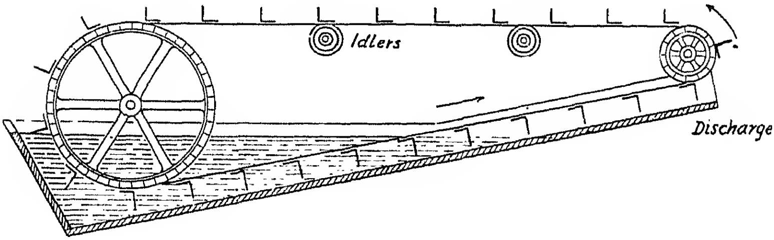
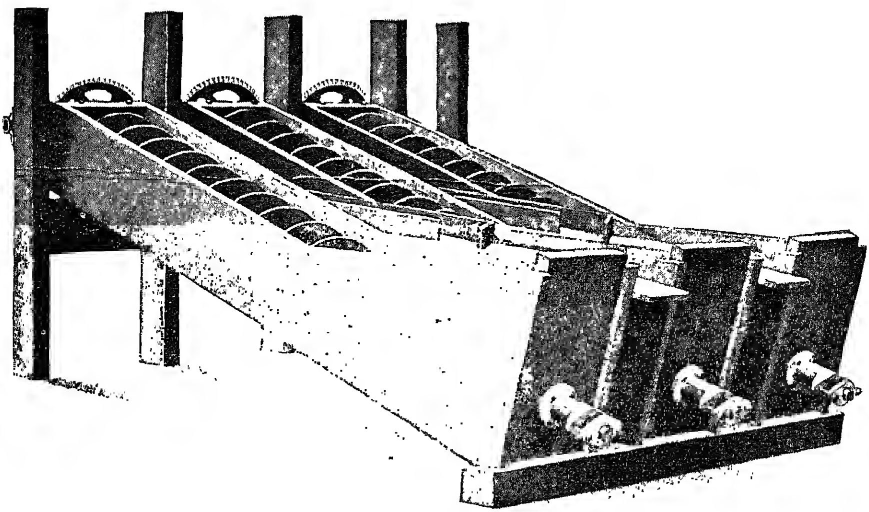


FIG. 107.—Drag-belt de-waterer.

rod having a to-and-fro movement. One of the best of this type is shown in Fig. 100 and described on p. 396.

Archimedean screws (Fig. 108) are extensively used for removing sand from separators and settling pits. They depend on the fact



Lewistown Foundry Co., Lewistown, U.S.A.

FIG. 108.—Screw de-waterer.

that as the sand is raised by the screw the water will tend to separate and will fall off the screw as the latter rotates. Such screws are not highly efficient as drainers, but they are so convenient as conveyors that their deficiencies are tolerated. A

particularly good combination of washer and sand separator in which a screw is used is the Freygang machine (p. 390).

Rotary drainers are comparatively novel. One of the most ingenious methods is used in Rikof's washer (Fig. 96), in which the drainer consists of a steel cone fitted at its large end into a wide flange which is in turn connected to a nearly horizontal shaft which is slowly rotated when in use. The cone has a number of metal blades forming pockets so arranged that the top edge of each blade is horizontal when it reaches the horizontal plane of the axis of the cone. This provides a truly horizontal overflow for the water separated from the sand. When the drainer is in use, as each pocket passes under the discharge from the cylinder it is filled with sand and water; the sand rapidly settles, and as the cone revolves, the water is poured off at the small end, leaving the sand very well drained. The sand then passes round and is discharged at the other side of the cone in a damp state. For effective working, the machine must be properly adjusted and driven at a speed which has been found by experiment to be the best for the local conditions.

All the foregoing methods yield a wet sand. They are useful in separating the sand from a relatively large volume of water and delivering it in a solid yet very wet condition. They may, therefore, be regarded as preliminary machines, and are of great value for removing the bulk of the water; the remainder must usually be removed by some other of the means described in the following pages.

Filtration is sometimes employed for drying sandy materials, and has the advantage of producing a drier product than simple sedimentation. The filters generally used for sand consist of a sheet or bag of some porous material, such as cloth or gauze, upon which the wet sandy material is poured; the water passes through the filter and escapes, leaving comparatively dry sand behind. Various devices are used in order to increase the rate of filtration, and some filters are provided with means to remove the dry sand automatically. In considering these appliances, it is necessary to remember that sand is highly abrasive, so that the wear and tear on the filtering medium is very great, and as the filters are expensive to purchase, it is often cheaper to use some other means of removing the water from the sand. Under some conditions, on the contrary, as when the sand is contaminated with salt and the supply of washing water is limited, or when only hard water is available, a filter forms the best means of removing the greater part of the water which cannot be separated by natural drainage or by sedimentation.

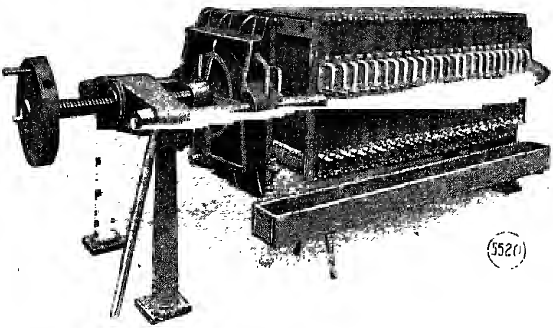
The chief types of filters used for sand are: filter-presses, rotary filters, draining belts, and centrifugal separators.

Filter-presses consist of a series of stout sheets of closely woven cotton, the sheets being folded into the form of bags, which are then fixed in series in a long frame. The material to be dried

is run into the bags, which are then closed, and pressure is applied to the whole series by means of a screw, so as to squeeze or press out the water, after which the press is again opened and the "cakes" of dried material removed. A press of this kind is shown in Fig. 109. Filter-presses are also made in which the mixture of sand and water can be pumped under pressure into the "bags"; this is a great advantage, of which full use should be made whenever possible. A pressure of 30-60 lb. per sq. in. is necessary for filling.

The time taken to operate a filter-press is generally about thirty minutes per run, the cakes produced being 1½-4 in. thick.

Filter-presses are not used for ordinary sands, but they are extensively employed for removing water from fine sediments



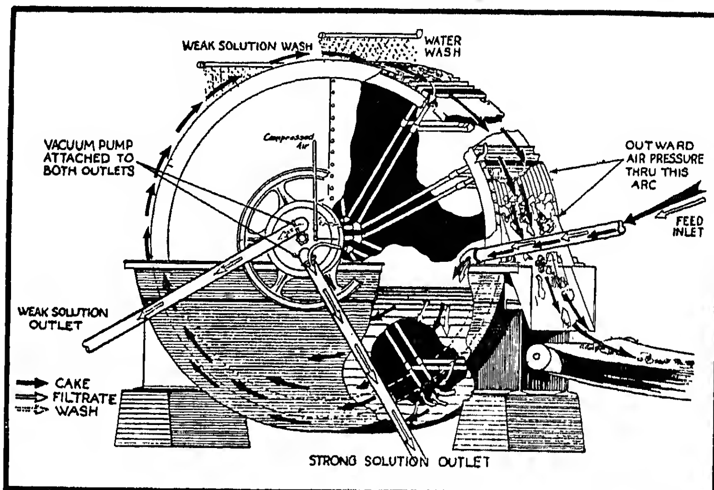
Manlove, Alliot & Co., Ltd., Nottingham.

FIG. 109.—Filter-press.

such as gold slimes, etc., which are produced by reducing rocks to the state of sand.

Rotary filters do not employ much, if any, pressure, but are usually worked by means of a vacuum pump. They generally consist of a large drum covered with cloth or other filtering medium on to which the wet material falls. The water is drawn through the cloth by means of a partial vacuum in the interior of the drum, whilst as the drum revolves the de-watered material is removed from the cloth by a scraper. In some patterns of rotary filter, the cloth is then washed as the drum rotates, and is afterwards ready for further filtration. In a well-designed rotary filter the action is, in effect, continuous. Several patterns of rotary filter are available. Thus in the one shown in Fig. 110 and made by the Oliver Continuous Filter Co., the hollow drum has on its periphery a series of compartments each independently connected to a vacuum pump. The bottom of each compartment consists of the filtering medium. In use, the drum is rotated in a V-shaped trough containing the liquid to be filtered, which is agitated so

as to keep the solid matter in suspension. As each compartment enters the liquid, a thin cake from $\frac{3}{16}$-$1\frac{1}{2}$ in. thick, according to the nature of the material, forms on the surface of the drum. On leaving the trough, the water in the cake is drawn through the filtering medium and the de-watered cake may, if desired, be washed by suitably arranged jets or sprays of water. After the cake has been carried past the washing sprays by the further movement of the drum, the vacuum is cut off and compressed air injected so as to force the cake away from the surface of the drum and facilitate its removal by scrapers. The clean compartments again dip into the liquid in the trough and the process is repeated.



Oliver Continuous Filter Co., London.

FIG. 110.—Vacuum filter.

Thus, each compartment produces one cake of material for each revolution, so that the output will depend on (*a*) the diameter of the drum; (*b*) the number of revolutions per minute; and (*c*) the thickness of the cake produced. According to the nature of the material treated, the output varies from 200-2500 lb. per sq. ft. per twenty-four hours. Ore slimes and floatation concentrates are usually de-watered at the rate of 500-600 lb. per sq. ft. per twenty-four hours.

Vacuum filters are chiefly employed for metalliferous sands or slimes or for other fine material for which the ordinary methods of sedimentation are not sufficiently rapid, or which do not give a sufficiently sharp separation.

Draining belts are sometimes used for drying sand, etc. They consist of an endless belt of stout twill cloth or similar material mounted on rollers like a belt conveyor (p. 328). The water

draining through the belt is caught in a trough below and led away, whilst the de-watered material is removed by a scraper placed near one of the pulleys. These belts soon become clogged and are by no means satisfactory dryers. Their only recommendation is that they convey the material as well as drain it. Attempts to compress the material on the belt by means of rollers have not been generally satisfactory.

Centrifugal drying may be employed for fine sediments, though it is, in most cases, too expensive except for valuable materials. The apparatus used is known as a centrifugal separator. It consists of a plain or perforated cylinder or basket, mounted on suitable supports or on a spindle, and rotated very rapidly by a belt and pulleys. If the basket is perforated and lined with cloth, felt, or other porous material, it is almost filled with the wet "sand" and the machine is then started. As the basket rotates with increasing rapidity, the action of centrifugal force drives both the water and the solid to the sides of the basket; the water passes through the perforations and the solid matter is retained by the filtering medium. If the speed of rotation is sufficiently high, a very well-drained material is formed.

If the basket is a plain one, it is made to rotate before adding any wet sand, and the latter is fed into the revolving basket at a steady rate. The "sand" flies to the walls of the basket more readily than the water and adheres thereto, whilst the water forms a hollow cone near the interior. If one or more small holes exist in the bottom of the basket, the clear water will pass out through these until the machine has been filled with de-watered sand. Any further quantity of wet sand then added will pass unchanged through the machine.

Various modifications of these two types of centrifuge are available, including one containing a filtering cone covering the holes for the exit of the water near the centre of the drum, so as to retain even the finest particles. If a mixture of a material consisting of grains of various sizes with a larger proportion of water is passed through a tall centrifugal drum, the solid matter is separated according to the size of its particles. In this way an efficient *grading* of fine sands can be satisfactorily effected in a suitable centrifugal machine.

It will be seen that the operation of a centrifugal machine is very simple. The amount of material forming a charge and correct rate at which the machine is to be run are easily ascertained after a few trials, and there is little to get out of order. The one drawback to the use of perforated baskets is that the solid material is liable to form a very compact mass through which the water travels with difficulty, and if the speed of the machine is increased, the density of the solid material is correspondingly increased. As a matter of fact, the use of baskets with perforated walls is the reverse of what should be employed, and the ideal arrangement is one in which the walls of the basket are quite plain, whilst the

outlet is near the centre of the basket. If this outlet is covered by a filter, the latter will have very little work to do as the bulk of the solid matter will adhere to the walls of the basket and only water which is almost clear will come in contact with the central filter. This arrangement has been patented by W. J. Gee, and is used in some of the filters supplied by Centrifugal Separators, Ltd.

Evaporation or Drying by Heat.—The drying of sands by evaporation is accomplished by applying heat to the wet material by means of (i.) a hot floor, drying pan, rotary dryer, or similar heating device; or (ii.) by passing hot air over the material. Occasionally both these methods are combined.

A *hot floor* consists of a shed or other building having a floor of bricks, concrete, or metal plates under which are numerous flues conveying either hot gases from a fire or steam from a boiler from one side or end of the floor to the other. By this means the floor becomes hot and any wet material placed upon it is dried by evaporation. Hot gases from a coal or coke fire are generally employed for such purposes, as steam heating is much slower, and there is, in most cases, no object in drying very slowly. Such floors are used for drying calcined quartz, ground phosphates, the concentrates obtained in recovering metals from sands, foundry sands, and similar "sands" which are not damaged by a slight overheating.

The materials, if sufficiently fluid, may be discharged through pipes on to the hot floors and removed by rakes when dried. Less fluid materials may be tipped on to the floor and distributed by means of rakes.

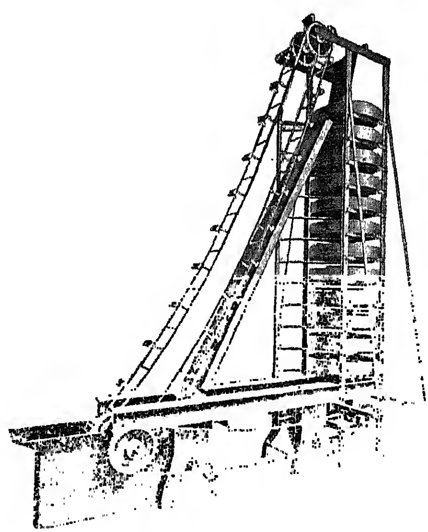
Drying pans are sometimes employed for sands. They are similar in principle to drying floors, but are on a much smaller scale. The pan may be of any convenient size and shape provided it is not too deep. It may be heated by a fire or by hot gases, or even by steam passed beneath it, but if the heating medium is at a temperature much above 150° C. the pan should be fitted with a mechanical stirrer so as to prevent the sand from being seriously overheated. Such pans are seldom economical, and are used chiefly on account of the rapidity with which they can dry moderate quantities of sand, without much regard for the cost of the heat used, or the labour employed. When large quantities of sand are to be dried regularly, pans are better replaced by some other more economical type of dryer.

Drying troughs, heated externally, may be regarded as pans of special shape. The sand is agitated and gradually conveyed from one end of the trough to the other by means of an Archimedean screw, or preferably by a shaft carrying a series of inclined blades. The open trough allows a large amount of heat to escape and is preferably replaced by a cylinder (see later).

Tower dryers are tall structures which receive the wet material at the top and dry it as it passes slowly by gravity to the bottom. One of the simplest forms of this type of dryer consists of a tall

wooden tower on two opposite sides of which are a series of steeply sloping platforms which act as "baffles." The wet sand falls on each of these baffles in turn, and in so doing it meets an upward current of hot gases from a furnace or other source of heat below. The tower must be so high and the baffles so numerous that the sand is dry before it reaches the bottom of the tower.

A much more rapid drying can be effected in a much smaller structure consisting of a series of iron pans or trays mounted one above another. The sand is fed into the uppermost pan, is carried slowly round it by means of a revolving scraper, and falls through an opening into the pan below where it is similarly treated, and eventually reaches the bottom of the series. The heat may be supplied in the form of hot gases, or still better, each pan may be heated by a separate gas-burner which ensures a much better application of heat to the sand, and with care does not cause any overheating. Such a dryer, made by Hardy & Padmore, Ltd., Worcester, and shown in Fig. 111, is very suitable for drying sands for use in glass manufacture and in foundries.



Hardy & Padmore, Ltd., Worcester.

FIG. 111.—Tower dryer.

A tower dryer used in America for sand-blast material consists of a series of tiers of pipes through which steam is passed at a pressure of about 90 lb. per sq. in. The wet sand is discharged from a bucket elevator on to the uppermost tier; being damp and coherent, it remains there until it dries, after which it falls on to each lower tier in succession until, when completely dry, it falls on to a belt conveyor which carries it to the storage bins.

Drying cylinders are very economical where a large amount of sand is to be dried. They consist essentially of a cylinder which may be vertical, horizontal or inclined, and either stationary, but fitted with revolving arms, or the cylinder itself may revolve slowly.

A *vertical drying cylinder* is really a special form of tower dryer (p. 408) and is constructed in a similar manner. The cylinder is usually stationary, but contains a series of trays above which are revolving arms, the arrangement being very similar to that in Fig. 111.

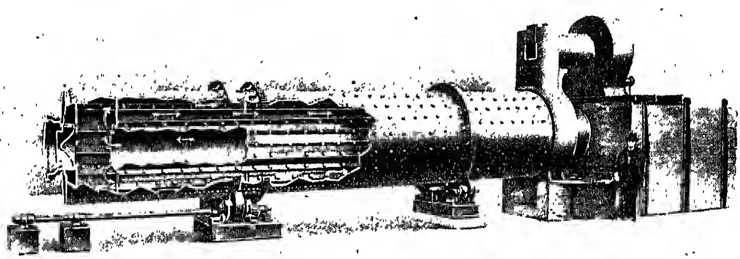
A *fixed horizontal cylinder dryer* must be provided with a series of revolving blades mounted on a central shaft, the blades being inclined so as to stir the material and carry it gradually through the cylinder. The latter is usually heated externally. If the cylinder rotates it must be provided internally with a series of baffles which impart a gradual forward movement to the material, and also lift it repeatedly and allow it to fall through the hot gases which pass through the cylinder. This type of dryer may be heated internally, or both internally and externally; it is greatly improved by being slightly inclined.

Inclined drying cylinders may be of either the fixed or revolving type, though the latter are preferable and more generally used. They have the advantage over the horizontal cylinders of requiring less power to drive them, and of being more compact and less expensive than some of the vertical ones, though a true comparison can only be made with reference to a particular sand dried to suit a given purpose. Inclined drying cylinders are usually heated both internally and externally, though those heated either internally or externally are in use and are quite satisfactory. The sand to be dried enters at the upper end of the cylinder and passes slowly along it, being raised and allowed to fall many times on its journey, until it passes out, fully dried, at the lower end. Care is required, especially with externally heated dryers, to avoid overheating; this is less likely to occur with internally heated dryers, though its possibility should not be overlooked.

One of the simplest forms of drying cylinders consists of an inclined cylinder rotating on the outside by gearing and heated by gases from a furnace at one end, which pass along the cylinder and are drawn off by a fan or chimney at the other end. The sand is introduced by means of a hopper at the end of the cylinder farthest from the furnace, and is carried by the rotary motion of the tube to the other end, where it falls into a receiver. Projections or baffles are fitted to the lining of the cylinder so as to break up the sand, lift it up repeatedly, and render the drying more effective.

A more complicated dryer is the Ruggles-Coles dryer shown in Fig. 112. It consists of two concentric steel cylinders capable of revolving about their slightly inclined common axis. The cylinders are connected at the middle by means of cast-iron arms, and at each end by means of adjustable arms. The inner cylinder projects beyond the outer at the upper end, and passes into a stationary air chamber which is connected to the hot-air flue of the furnace. The lower end of the cylinder is also connected by means of an opening in the bottom to a second stationary air chamber, which is provided with a damper in order to regulate the temperature. The hot gases are drawn by means of an exhaust fan through the inner cylinder, and then back through the annular space between the two cylinders, and finally brought through the flue leading to the fan. The sand is fed through a shoot into the space between the two

cylinders, and as the dryer revolves the sand is lifted by means of scoops attached to the inner surface of the outer cylinder and the outer surface of the inner cylinder, and falls from the surface of one cylinder to that of the other, this process being repeated as the sand travels to the lower end of the dryer, where it is discharged in



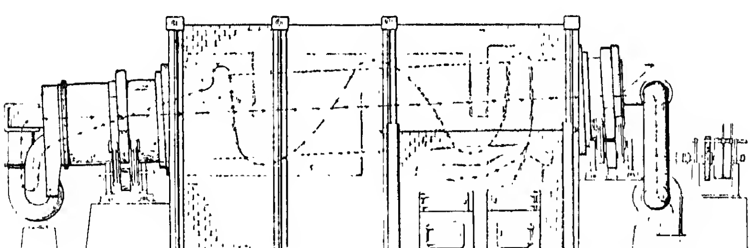
Boving Engineering Works, Ltd., London.

FIG. 112.—Ruggles-Coles dryer

a dry state. This type of dryer has been largely used for drying sand for glass and chemical manufacture.

The rotary dryer made by Manlove, Alliot & Co., Ltd. (Fig. 113), differs from that just described, inasmuch as the gases first pass around the inner cylinder containing the sand to be dried and then through the cylinder to a fan discharging into a short chimney.

In the rotary dryer made by Ord & Maddison, Ltd., Darlington,



Manlove, Alliot & Co., Ltd., Nottingham.

FIG. 113.—Manlove-Alliot rotary dryer.

the cylinder is suspended by endless steel chains from a shaft above and is driven by the frictional contact of the chains with the cylinder. The cylinder is provided with the usual scoops to lift the sand and carry it forward and is heated externally, and also by a blast of air from numerous perforations in a long pipe which passes longitudinally through the cylinder. The blast of air is particularly

useful for expelling the steam and for preventing condensation, but unless a catcher or trap is provided, much of the finest sand will be lost if a powerful blast of air is used. The dryer has been used very satisfactorily for drying sandstone previous to grinding it, as such treatment reduces the cost of grinding.

A good rotary dryer is somewhat costly to instal, but if well designed and sufficiently long to utilise the heat properly, it will soon pay for itself in cases where there is a sufficient quantity of sand to keep it fully employed.

In order to obtain the best results from a rotary dryer, which is probably the most efficient type available for large outputs, it is most important to take the following precautions: (*a*) The sand must not be overheated if it is to be used for foundry work, or for other purposes where a moderate degree of plasticity is required. (*b*) The temperature of the gases leaving the dryers should not be hotter than is necessary, or much waste of heat will result. (*c*) If the dryer is not heated externally it should be well lagged with good insulating material, or much heat will be lost. (*d*) A fan is preferable to a chimney for creating the necessary draught, as the latter can be much more accurately regulated with a fan. (*e*) The sand must be brought into the most intimate contact possible with the hot air, in order to ensure that the air is being used with the greatest economy; this is effected by suitably designed baffles or scoops and by keeping the cylinder as horizontal as possible, consistent with a sufficient forward movement of the material. (*f*) The material should be supplied to the dryer in small quantities at very frequent intervals, rather than in larger amounts at longer intervals. (*g*) The dryer must be large enough and long enough to do its work properly; short dryers are seldom efficient so far as fuel consumption is concerned. (*h*) The fuel must be fully burned, as partially burned gases involve a serious waste of fuel.

By taking sufficient care to observe these precautions, the maximum output may be obtained with a minimum expenditure of fuel and labour.

Sundry Dryers.—Various appliances may be used for drying small quantities of sand, especially where there is little risk of damaging it by overheating. Thus, in some works, the sand is left in any convenient warm place until it is dry.

A simple device, much used in American foundries, brickyards, and glass-works, consists of a small coke stove surmounted by an iron cone from the top of which projects a short chimney, the total height being about 3 ft. Around the cone and chimney is a cylinder of perforated steel, 3 ft. in diameter. The wet sand is placed in the cylinder and is stirred occasionally with a long poker. As it dries, the sand separates into individual grains, and these pass through the $\frac{1}{8}$-in. perforations in the cylinder and accumulate in a tray around the base of the furnace, from which it may be removed with a scoop. This dryer is not economical in fuel, but for drying a few hundred pounds of sand it is by no means extravagant, and

it is so simple to use and so strongly built as to do its work with little trouble or attention.

Effects of Overheating in Drying.—For many purposes the temperature attained by sand during the drying process is of no importance, but for foundry work, and less frequently for some other purposes, care must be taken to avoid an excessive temperature. This is chiefly due to the fact that some materials known as "sands" are in reality mixtures of sand and clay, and for their effective use the plasticity of the clay present must not be destroyed. As such destruction is readily effected by heating to a temperature much exceeding 120° C. (250° F.) the dryers used for such "sands" must not expose the sands to a higher temperature than that just mentioned.

Since any temperature below a red heat is not likely to damage a sand which is free from clay (*e.g.* most washed sands), it is usually more economical as well as more speedy to work the dryer at a relatively high temperature, as a smaller quantity of air or hot gases will then suffice to carry off the moisture in the sand.

CONCENTRATION BY WATER

Concentration forms part of the treatment of metalliferous sands, and consists in the removal of the siliceous material from the heavy minerals present. Some of the processes are similar in many respects to "washing" (p. 384), though the presence of the heavier particles renders some modification necessary. In many cases, a preliminary washing is desirable to remove the clay and "dirt" adhering to the sand; this washing is effected in the same manner as for ordinary sands (p. 384).

The principal washers used are sluices (p. 386), log washers (p. 386), mud-wheels (p. 386), wash mills (p. 388), and rotary washers (p. 389).

In washing, the lighter and smaller particles are removed by the water, but in concentrating, the particles of higher specific gravity are retained whilst those of lower specific gravity are carried off. In washing, separation is largely based on the size of the particles, but in concentrating, their specific gravity is the important factor.

Panning.—The simplest method of concentrating metalliferous sands, such as those containing gold, consists in panning as described on p. 256. The pans usually employed are about 18 in. across the top and $10\frac{3}{8}$ in. at the bottom, and hold about 20 lb. of material. A man will work 75-150 panfuls or $\frac{1}{2}$-1 cu. yd. of material per day; 100 panfuls or 18 cu. ft. is a good day's work. This method is, of course, slow and is only used for prospecting, mechanical appliances being used for washing the material on a large scale.

Buddles.—A very old method consists in using a buddle, which

may be either rectangular or circular. A box-buddle (Fig. 114) consists of a rectangular trough 10-15 ft. long, 4-6 ft. wide, and 1 ft. 6 in.-2 ft. 6 in. deep, inclined at an angle of 4-10 degrees. At the top is a head-board 15-20 in. wide, inclined at an angle of 15-20 degrees, and fitted with projecting pins to distribute the slurry over the surface of the buddle. The material to be treated is mixed with water and allowed to flow down the buddle; during its passage it is agitated by labourers with long rakes, the heavy minerals collecting at the top of the incline and the lighter ones at the bottom. Rectangular buddles are similar to sluices, but are much wider.

A circular buddle (Fig. 115) consists of a shallow circular pit,

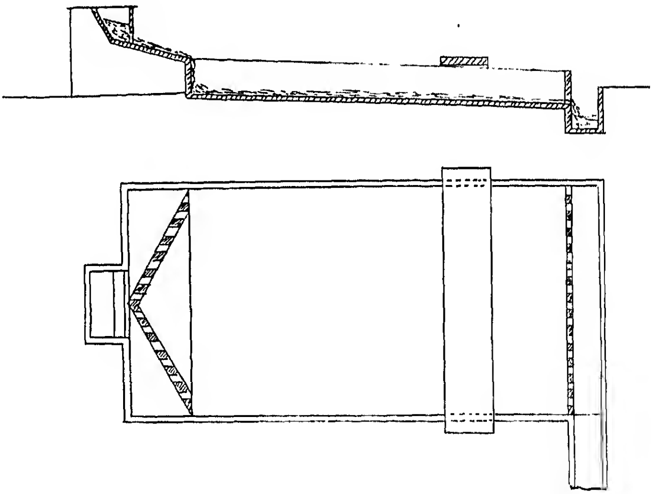


FIG. 114.—Rectangular or box buddle (section and plan).

with a raised centre, having a depression or cup in the middle. The floor of the pit slopes away gradually at an inclination of 8-10 degrees, and is surrounded by a gutter or launder. The sand and water is poured into the cup in the centre of the buddle and gradually overflows down the sloping bottom of the pit. A number of brushes suspended over the buddle, revolving at 10-12 revs. per min., spread out the material as it overflows, and prevent the particles from settling too rapidly. In this way the heavy particles settle near the upper end of the slope, whilst the lighter grains of quartz, etc., are carried to the bottom and collected in the gutter, from which they are removed at intervals. The operation is continued until about 9-12 in. thickness of material has collected on the table. The material is then separated by drawing concentric rings and digging out the material between each ring separately. If the sand is deposited too rapidly at the

upper end of the table the slurry should be supplied to the table in a thinner slip, or should be supplied more quickly. If, however, it collects too quickly at the lower end of the table, the slurry may be too thin or is being supplied at too great a rate. A round buddle 18-25 ft. in diameter, the arms of which make 5-10 revs. per min., will have an average output of $1\frac{1}{2}$-3 cu. ft. per min., will carry 28-56 lb. of material, and will require three to ten hours for each batch of material.

Some circular buddles are concave instead of being convex

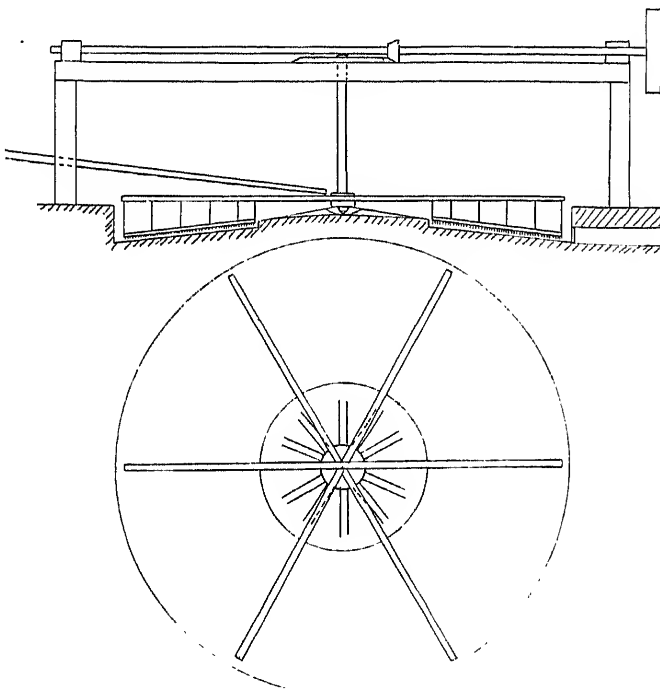


FIG. 115.—Circular buddle.

and cause the heavy minerals to collect at the circumference, whilst the lighter grains pass to the centre. Such buddles are useful for treating materials from which the greater part of the gangue has been removed by partially concentrating them in a convex buddle.

Sluicing is a very simple method of concentration. A sluice is a wooden or iron trough, about 12 ft. long and 12-24 in. wide, fixed at an inclination depending on the character of the material, but usually between $1\frac{1}{2}$ in. and 21 in. per 12 ft. The slurry, composed of sand and water, is fed in at the upper end of the trough

and flows down the incline, the heavy particles settling at the top and the lighter ones being carried to the lower end of the trough. For treating sand of 30-40 mesh a sluice box about 2 ft. wide, with an inclination of $1\frac{1}{2}$ in. in 12 ft., is usually satisfactory, but a sand of about 4-6 mesh requires a slope of about 3 in. in 12 ft. Some rough measurements have shown that the output varies as the 1·75 power of the slope.

It is customary to make the sluice boxes 1 ft. wide for each 2 cu. yds. of material treated per hour, and to supply 3000 gall. of water per cu. yd. of material, when the slope of the sluice box is 6 in. in 12 ft. The output varies so greatly that no reliable figure can be given, though it is customary to state that a *long tom* or short sluice can deal with 3-10 cu. yds. of material per day.

Sloping Table Concentrators are of various patterns. One type, termed the *sweeping table*, consists of a table 12 ft. long and 4 ft. wide, inclined at an angle of 10-12 degrees for coarse sand and 5-6 degrees for fine sand. The slurry is allowed to run down the table for four minutes, and the residue is washed by passing water over the table for two minutes, after which the concentrate is removed. Such tables have a capacity of 4-30 cwts. per twenty-four hours. In some cases the tables are covered with a blanket or sheet of canvas on which the concentrated material is collected.

The *cradle* or *rocker* type of concentrator consists of a box with a working surface about 40 in. long by 16 in. wide, the depth varying from 12 in. at one end to zero at the other. Across the box or table are riffles or baffles about $\frac{3}{4}$ in. high. The material to be concentrated is introduced into the deep end of the box and a stream of water is poured over it, whilst the box is given a rocking motion from side to side. The particles are carried along by the water, the heavier ones being caught by the riffles, whilst the lighter particles are washed away. With a good rocker and suitable material 2-3 cu. yds. of material can be treated per day and about 90 per cent of the heavy particles retained.

Rockers are largely used in connection with placer or alluvial gravels and sands containing gold. For this purpose it should be longer than the ordinary mining rocker and inclined less steeply. A strip of Brussels carpet fixed on the floor of the rocker enables the fine gold to be retained more easily.

The *percussion table* concentrator consists of a shallow, suspended trough, 9-12 ft. long and 4-5 ft. wide, inclined at 5-8 in. per 6 ft. for fairly coarse sand and 2-3 in. for very fine silty materials. By means of a crank the table is moved forward $\frac{1}{2}$-4 in. and is then allowed to fall back against a stop, this motion being repeated twelve to eighty times per minute, thus causing the heavy particles to be concentrated at one end of the table, from which they may be removed when a sufficient quantity is deposited.

A modification of this method of washing metalliferous sands, called *tossing* or *tozing*, consists in stirring the partially purified material with water in a tub about 30 in. deep, 48 in. diameter

at the top and 42 in. at the bottom, and then allowing it to settle, whilst one or more hammers deliver eighty to one hundred and fifty blows per minute on the outside of the tub. After the whole of the heavy materials have settled, the supernatant liquid is poured off, the upper layers of material being discarded, as they consist almost entirely of light minerals, the heavy minerals having settled first. . The process may be repeated as often as it is necessary for the purification of the sand. This type of concentration is chiefly used in separating tin from crushed rock or from tin-bearing sands.

The devices described above are all intermittent, and they must be stopped at intervals in order to remove the material collected. Where a large output is required it is preferable to employ a continuously acting separator, as this secures a greater output in the same time without impairing the quality of the separation.

Revolving buddles are similar to the fixed buddles already described, except that the table rotates and the slurry is only supplied to about half the table, the remaining section being used for wash water. The tailings flow down one-half of the table, the "middlings" flow over the next third, and the "headings" are cleared off by fixed brushes or jets of water just before each revolution of the table is completed. Each portion so removed passes into its own division of the outside receiver. Buddles of this kind are rotated in one to five minutes. A buddle 10-16 ft. in diameter will deal with 6-8 tons of sand in twenty-four hours, and requires about 15 cu. ft. of water per min. When treating very fine material only about 8 cu. ft. of water per min. are required, and the output is 2·8-3·6 tons per day: Concave buddles are sometimes employed, the slurry being supplied over about one quarter of the circumference.

A revolving buddle 15-25 ft. diameter, with the arms making $\frac{1}{4}$-1 rev. per min., will deal with $1\frac{1}{2}$-3 cwt. of "pulp" per min., carrying 4-7 lb. of solid matter per cu. ft. of pulp. The power required to operate such a buddle is $\frac{1}{8}$-$1\frac{1}{2}$ h.p.

Side-percussion tables are inclined tables similar to those previously described, either with or without riffles, and sloping at an angle of about 6 degrees for sand and 3 degrees for fine slime. The material is supplied to the table at one corner, whilst the wash water flows down the rest of the table. In the Rittinger apparatus the table is struck at the side by means of a cam motion about 70-80 times per min., the table being moved about $2\frac{1}{2}$ in. at each blow when used for sand or $\frac{3}{4}$-1 in. when used for slime; the knocking causes the material to be spread across the table according to its specific gravity, and it is then carried down the table by the wash water, being guided by baffles into different receivers. In the *Lührig table* (Fig. 116) a greater number of smaller knocks are given, usually about 150-210 per min., the movement being $\frac{1}{6}$-$1\frac{1}{2}$ in. A belt is fitted over the inclined frame, moving at right angles to the direction of the water, the slurry being supplied to

one end of the belt and wash-water to the rest. A Lührig concentrator with a belt surface 12 ft. by 3 ft. 6 in., travelling at the rate of 8-12 ft. per min. and struck at 160-180 blows per min., has an output of 2-8 tons per twenty-four hours. It requires $\frac{1}{4}$-$\frac{1}{2}$ h.p. to operate it.

The *Wilfley table* (Fig. 117) consists of a rectangular table tilted so that the material flows diagonally across it, the sand and water being poured on to it at one corner. The upper surface is covered with linoleum, on which strips of wood are nailed so as to form riffles or baffles designed to aid in separating the grains of heavy

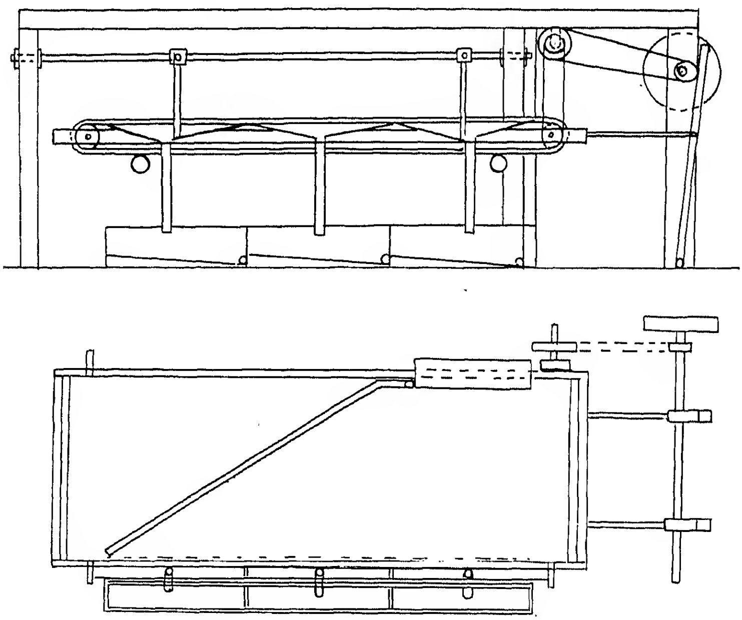


Fig. 116.—Lührig table (section and plan).

minerals. Near the corner, where the slurry is fed on to the table, the riffles are short, whilst on the opposite side they stretch nearly to the lower end of the table. The riffles are about $\frac{3}{8}$ in. deep at their upper ends and taper to nothing at their lower ends. The table is struck at the rate of 24 strokes of $\frac{5}{8}$-1 in. per min.; this causes the various minerals present in the sand to arrange themselves during their passage across the table according to their specific gravities. This separator is chiefly suitable for particles between 16- and 30-mesh. The usual output is about 1-2 tons per hour, for a table 16 ft. long, 6 ft. wide, tapering to 3 ft., with about 240 strokes each $\frac{3}{4}$ in. long per min. About 1 h.p. is required to operate it.

Grooves are used instead of riffles in the table of the Card Concentrator, it being claimed that they are more advantageous for rough concentration.

The chief difficulty with these tables is that small particles of high specific gravity tend to act in the same way as larger particles of low specific gravity, so that some of the material is lost, especially as in many sands the high specific gravity particles are usually smaller than those of lower specific gravity. This may be largely avoided by screening the particles so as to ensure all those on the table at any one time being sufficiently uniform in size.

In Brazil, monazite sand is first treated by the wet process and afterwards magnetically concentrated.

Tin and tungsten placers are often treated on tables of the Wilfley type.

In some percussion tables, the blows are applied to the lower

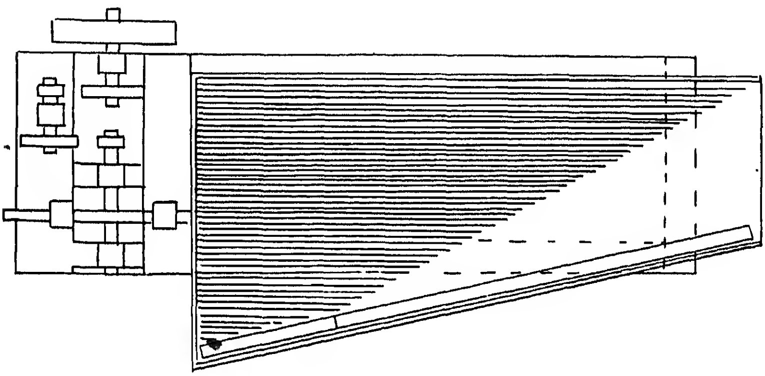


FIG. 117.—Plan of Wilfley table.

end of the table instead of the side, so as to drive the material upward, whilst the descending water washes the finer grains away. In such tables the heavy particles gradually mount upward and are discharged over the top of the table. This type of table is suitable for material between 40- and 80-mesh. The Gilpin County Concentrator is of this class, and is about 7 ft. long and 18 in. wide, the lower $5\frac{1}{2}$ ft. being flat and sloping about $\frac{3}{8}$ in. per ft., whilst the upper part is concave so as to receive the concentrated material. This table receives 120-180 shocks per min., the amount of movement being $1\frac{1}{2}$-3 in.

Vanners consist of endless belts which slope slightly, the material travelling upwards, whilst the water flows downwards and carries away the lighter particles. The belt may be pulsated either by end or side percussion.

The Frue vanner (Fig. 118) is a side-percussion concentrator, about 4 ft. wide and 12-27 ft. long, with a slope of $\frac{1}{4}$-$\frac{1}{2}$ in. per ft. It moves at the rate of 2-7 ft. per min. and is struck 180-200 times

per min., with a movement of 1 in. This machine only requires $\frac{1}{2}$-$\frac{3}{4}$ h.p. to drive it, and is capable of separating 5-10 tons of material per twenty-four hours, using 1-3 gallons of water per min.

Jigs may be used for particles over $\frac{1}{32}$ in. Very fine grains are not readily separated by jigs on account of the excessive amount of friction between the grains and their tendency to form compact masses, which only break up with difficulty. For this reason, fine grains are best treated in some other form of concentrator.

It is preferable for the material to be graded or sized to some

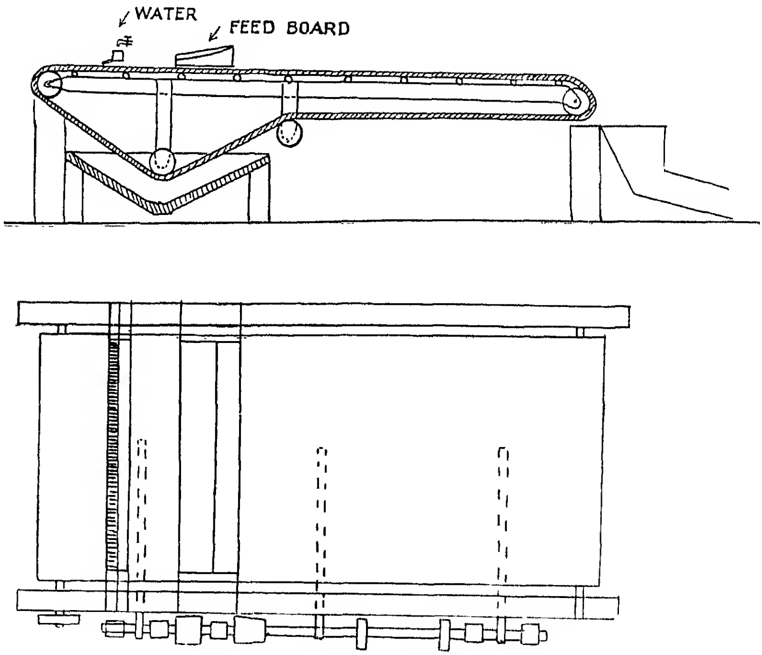


Fig. 118.—Frue vanner (section and plan).

extent before it enters the jig, as the latter separates the grains according to their specific gravities, and if grains of numerous sizes are present, large particles of low specific gravity may act in the same way as small particles of high specific gravity and only a poor separation will be effected.

A jig consists of a screen of brass wire or perforated steel plate,[1] upon which the material to be treated is placed so as to be subjected to alternate ascending and descending currents of water, which are produced either by a piston which forces the water to rise and fall

[1] Steel should not be used when sulphides are present, as any oxidation of the latter with the formation of sulphuric acid would destroy the steel.

through the sieve (Fig. 120), or by reciprocating the sieve vertically in a chamber containing water (Fig. 119). Where the sieve moves, the amount of movement varies from $\frac{1}{2}$ in. for a fine material to 3 in. for a coarse one, and the number of movements per minute varies from 150 for fine to 100 for coarser particles. Movable sieves are generally used in jigs worked by hand, but the more modern power jigs are usually fitted with stationary sieves, the material being agitated by the motion of the water. For such jigs the size of the sieve is suited to the output required, and is generally

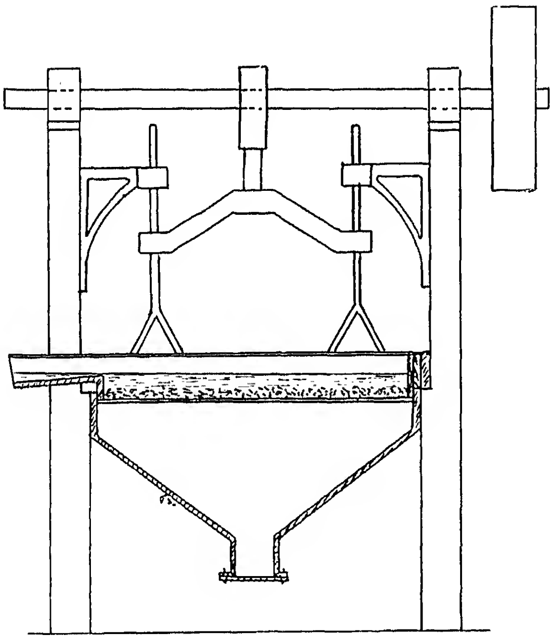


FIG. 119.—Harz jig.

2-4 ft. long and 1-3 ft. wide, and is mounted 12-18 in. below the top of the hutch. The depth of solid material on the sieves of a jig concentrator is usually about 4 in. Where very fine material is being treated in a jig, a bed of material having about the same specific gravity as the fine material is necessary to prevent the fine material from falling to the bottom of the jig and being lost; for coarse particles this is not essential.

The piston for agitating the water is usually placed in a chamber alongside the jig with a baffle wall 7-12 in. deep between. The piston should not fit tightly, but should have $\frac{1}{8}$-$\frac{1}{2}$ in. clearance all round. The oscillations may be perfectly regular, or there may be a rapid downstroke and a slow upstroke, as in the Collom jig. In

the Baum jig the pulsations are caused by compressed air at a

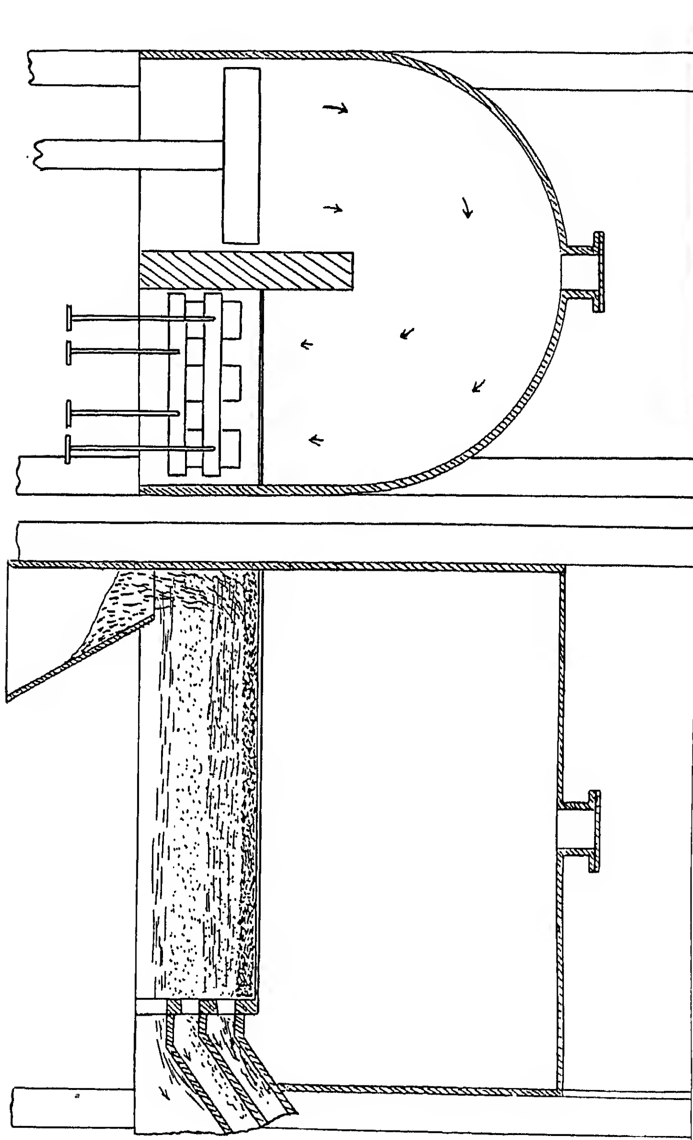


Fig. 120.—Jig concentrator (longitudinal and cross sections).

pressure of $1\frac{1}{2}$-2 lb. per sq. in., which produces 75-110 strokes per min. This jig is particularly suitable for grains smaller than

$\frac{7}{16}$ in. diameter. In this jig a specially thick layer of material is kept on the sieve.

The water chamber or "hutch" containing the sieve may be of wood, wrought-iron sheets, or of cast iron, the first being cheap but liable to decay, and the last rather heavy, but otherwise satisfactory. The shape of the hutch varies; a pyramidal or tapering hutch is very convenient, as it brings the deposited material to one point, from which it can readily be removed periodically. This form of hutch is used in the Bilharz and various other jigs.

The action of a jig is as follows: When the particles are subjected to the ascending and descending currents of water, they arrange themselves according to their specific gravities and form a series of beds with the lighter materials above and the heavier ones below. In this way the heavy metalliferous grains are separated from the lighter siliceous material. The removal of the separated grains may be effected in two ways—(*a*) the light grains may flow over a "gate" in the side of the chamber, whilst the heavy grains collect on the sieve or pass across the sieve and are removed through a second aperture at a lower level than the tailings gate; or (*b*) the heavy grains may pass through the sieve and be collected in the water chamber, whilst the lighter grains or tailings are removed over a gate above the sieve as before.

The effectiveness of a jig depends on (*a*) the quantity of the material to be treated at a time, its density and the size of the grains, as well as the ratio between the diameters of the largest and smallest particles; (*b*) the supply of water and its relation to the amount of pulp treated; (*c*) the rate of oscillation of the water or the amplitude of oscillation; (*d*) the speed of the upward and downward currents; and (*e*) whether the jigging is through the sieve or over it, and, in the former case, the nature of the bed, its depth, and the size of the particles composing it.

Table LXXII., due to T. Sopwith,[1] gives the particulars of the jigs used for grains of various sizes, the jigging being effected *over* the sieve.

TABLE LXXII.—DATA FOR JIGS

Diameter of Particles.	Oscillation per Minute.	Depth of Oscillation.	Quantity treated per 10 hr.
		ins.	cwt.
0·4 -0·28	96	$2\frac{1}{4}$	244
0·28-0·2	86	2	220
0·2 -0·1	84	$1\frac{3}{4}$	112
0·1 -0·06	82	1	71

The amount of material dealt with in a jig concentrator depends on the area and especially on the width of the sieve. Outputs from

[1] *Proc. Inst. Chem. Eng.* xxx. 106.

0·15-9·6 tons per sq. ft. per twenty-four hours may be obtained,

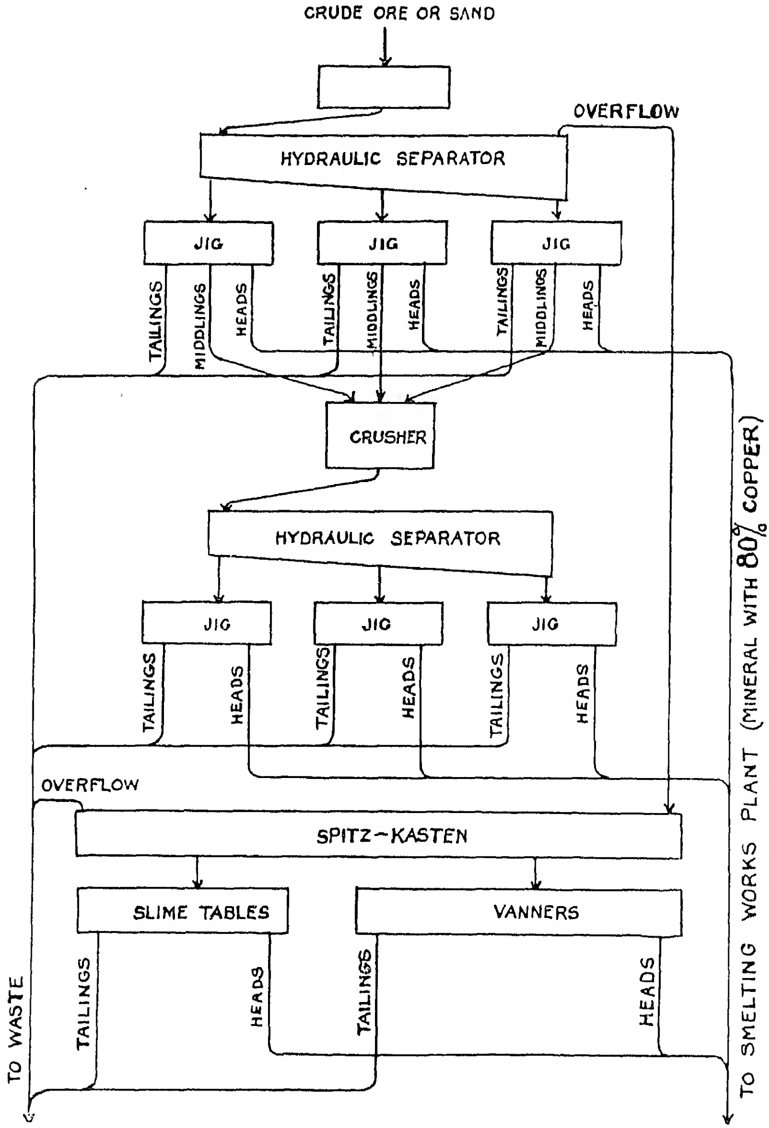


Fig. 121.—Ore table.

0·5-2 tons being the average. About 1½ h.p. is required for a one-sieve jig, and an extra ½ h.p. will usually be needed for each

additional sieve. The amount of water used varies considerably, a three-sieve jig requiring about 34,000 gallons per twenty-four hours.

If desired, jigs may be worked in series, the material from one jig being discharged into a second or third so as to secure a more effective separation.

The arrangement of the various machines required for concentrating a sand or crushed rock containing only a small proportion of valuable mineral is shown in Fig. 121, which represents those used for dealing with an ore containing only 2 per cent of copper.

CONCENTRATION BY FLOATATION[1]

Concentration by floatation is based on the fact that many substances when in the form of powder will float on water, although they have a higher specific gravity than water. Nor is it necessary that the solid particles should be coated with a film of grease; though such a film will usually increase the floatability.

The various floatation processes may be subdivided as follows:

1. Oil floatation, utilising differences of surface tension in an oil-water medium where the particles are buoyed up by oil, *e.g.* First Elmore process.
2. Film floatation, utilising differences of surface tension on particles at an air-water interface, *e.g.* De Bavay and Macquisten processes.
3. Adhesive processes, utilising differences of surface tension between particles of oil and grease, causing differential adhesion to oiled or greased surfaces, *e.g.* Murex and Cattermole greased-plate processes.
4. Froth floatation, utilising differences of surface tension at gas-water interfaces, where the particles are buoyed up by bubbles of gas.
   - (*a*) Where the bubbles are produced by chemical action, *e.g.* Potter and Delprat processes.
   - (*b*) Where the bubbles are produced by releasing the air dissolved in water, *e.g.* Elmore vacuum process.
   - (*c*) Where the bubbles are produced by mechanical means, *e.g.* Minerals Separation, Callow, Janey, K. & K., and Rork processes.

Each of these processes has its own sphere of usefulness, but for sands and the like containing only a very small proportion of valuable material, the surface area of water or oil required to float any particles of metal or ore is so enormous in proportion to the weight of the material to be floated that, instead of the water surface being horizontal, it is much more convenient if it is divided into a multitude of hollow cells, as in a froth or foam. To produce

[1] According to the *Oxford Dictionary*, the customary method of spelling this word—"flotation"—is "etymologically unjustifiable."

this froth commercially it is necessary to add small quantities of a suitable substance such as soap, saponin, amyl alcohol, certain oils such as turpentine and eucalyptus, aromatic compounds such as camphor, certain benzene derivatives such as aniline, cresol, phenol, and many other substances.

When to water which has acquired the property of foaming is added a mixture of ore and quartz or other siliceous matter, and a foam or froth is created by shaking or other means, the ore will float more readily than the quartz, so that a separation will be effected.

The froth usually requires to be stabilised by the addition of a saturated hydrocarbon such as paraffin oil, which enlarges the angle of contact between the air-liquid surface and the water-solid surface.

The quartz may be rendered still less floatable, and its separation from the ore improved, by the addition of a little sulphuric acid, soda, sodium silicate, or some other salt.

Hence, on using floatation as a means of separating certain minerals from the gangue (quartz, etc.) in a sand, there are three factors to be adjusted relative to one another—(*a*) the cresol or other froth-producing substance; (*b*) the paraffin oil or other froth stabiliser; and (*c*) the acid which reduces the floatability of the gangue. Sometimes one agent will discharge two duties: thus, sulphuric acid not only deflocculates quartz particles and renders them unfloatable, but it increases the floatability of zinc blende, whilst sodium silicate behaves similarly with regard to copper sulphide ores. Eucalyptus oil, oleic acid, turpentine, and many other oils act both as froth-producing agents and froth stabilisers.

The proportion and nature of the salts in the water used also affect the results. Thus, if soap is used the water must be soft.

There is no general rule that ores are floated and gangues unaffected; almost any substance can be made to float if suitable chemicals are used, and the problem in each case is to find what agents will most effectively separate the substance which it is desired to float from the others which are present in the crude sand.

The proportions of reagents required are usually quite small; indeed failure more often occurs from using too much than too little. About 3 lb. of oil, up to 20 lb. of acid, or 3-4 lb. of sodium silicate per ton of ore, is all that is usually required.

The sand or crushed rock is mixed with about four times its weight of water and agitated by rotating blades. During the agitation the reagents are added, and after sufficient mixing and aeration the frothing liquid is transferred through an aperture in the side of the vessel to another vessel containing still water. Here the bubbles loaded with mineral particles rise and form a froth which is removed, whilst the particles of gangue sink to the bottom, and may, if required, be carried into another vessel for a repetition of the treatment.

The efficiency of the process is such that 90 per cent of copper sulphide in an ore containing only 0·5 per cent of this material can

be recovered on a commercial scale. The process is particularly useful for ores and sands of very low grade which could not be concentrated economically by any other method.

In the use of floatation as a method of separation, practical procedure has outrun scientific knowledge, so that whilst a large number of papers and several books have been written on the practical aspects of the subject, the scientific side has been largely neglected. Many of the statements made in explanation of the underlying principles do not bear the test of experiment, and until there is more consensus of opinion on the precise nature of the underlying principles, no brief yet comprehensive explanation of them can be given. It does not appear certain, however, that when a substance has been deflocculated or reduced to a state in which it will remain suspended in water it can no longer float on the surface. On the other hand, flocculated substances will float if the aeration is sufficient. Hence, all floatation problems resolve themselves eventually into the flocculation and aeration of the substance it is desired to float ; thus, flocculation is effected by the addition of a chemical substance which must depend largely on the colloidal character of the substance under consideration. The aeration is similarly effected by the addition of a suitable froth stabiliser as well as by the use of suitable mechanical means. The deflocculation of the gangue must be brought about by another reagent, which, like the one used for flocculation, must depend on the chemical and physical properties of the substance on which it is to react.

When once the necessary conditions as regards the reagents to employ and the proportion of each have been determined for any given material, the process of concentration by floatation is a simple matter.

CONCENTRATION BY AIR

Concentration by air is sometimes used for dry material, the air being used either as a continuous blast or in a succession of gusts. For the former, an air separator is used.

The purification of sand by means of a current of air, especially in connection with an air separator (p. 466), is seldom possible when clay is present. Fine particles of a non-plastic nature may, however, be efficiently separated by this means, as a current travelling at the rate of 4·4 ft. per sec. will stir up the sand and carry off all the particles less than 0·1 mm. diameter. Larger particles can seldom be separated efficiently by means of air.

A pulsating air separator is often used for concentrating metalliferous sands. A dry concentrating table, in which air is used, consists of a table under which is an air-motion blower, which causes air to enter the table from below and pass through a pervious cloth top, forming an air film under pressure on the upper surface of the cloth. This air film causes the minerals to arrange them-

selves vertically in order of their specific gravities, the heaviest being at the bottom. A reciprocating motion is also imparted to the table, which causes the minerals to arrange themselves into zones. This method has been used for concentrating monazite sands in Travancore.

Although air separators (p. 466) may also be used for concentrating heavy minerals, they are chiefly used for grading or sizing.

MAGNETIC CONCENTRATORS

Concentration by magnetic means is often both cheap and efficient. Magnetic separators may be divided into

(*a*) Lifting separators.
(*b*) Retaining separators.
(*c*) Deflecting separators.

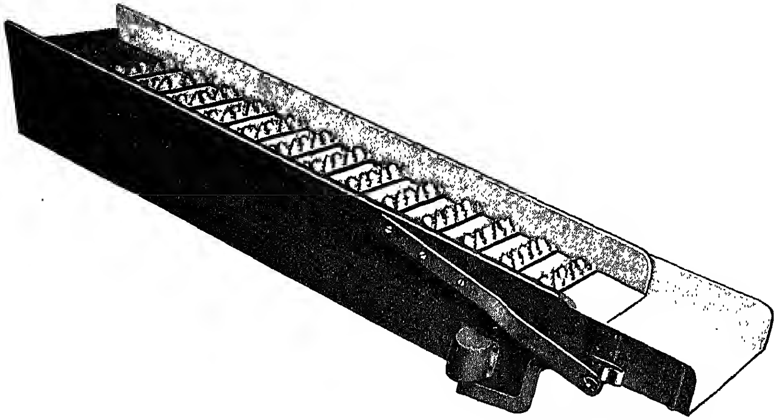
In each case the separation depends on the fact that some substances are more readily attracted by a magnet than others. Table LXXIII. shows the maxima of magnetic susceptibility of various substances.

TABLE LXXIII.—MAXIMA OF MAGNETIC SUSCEPTIBILITIES OF VARIOUS SUBSTANCES, BY VOLUME, IN C.G.S. UNITS[1]

Material.	Locality.	Magnetic Susceptibility.
Soft iron	..	400
Magnetite (pure crystallised)	Piedmont	3·12
Magnetite	Hay Tor, Devonshire	1·44
Magnetite	Altenfjord, Norway	0·27
Magnetite	Lake Champlain, U.S.A.	0·234
Magnetite (altered carbonate, impure)	Bettwys Garmon, Carnarvon	0·06
Red Haematite	..	0·00073
Red Haematite (crystallised)	Cumberland	0·00017
Specular Haematite	Nova Scotia	0·00106
Specular Haematite	..	0·0005
Brown Haematite	..	0·00042
Brown Haematite (pure crystallised)	Nova Scotia	0·00011
Franklinite	New Jersey	0·0037
Franklinite	New Jersey	0·00253
Ferrous sulphide	Artificial	0·064
Spathic ore	..	0·000559
Clayband	..	0·00069
Impure carbonate ore	Northamptonshire	0·00056
Ilmenite	India	0·00147
Monazite	Travancore	0·000069
Zircon	Ceylon	0·00000055
Pleonaste	..	0·000102
Galmite	..	0·000054

[1] Due to E. Wilson.

The susceptibilities of common non-ferrous minerals—*e.g.* mica, quartz, felspar, calcite—are less than 0·000001; those of

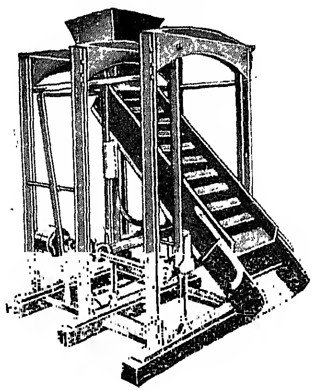


Wm. Boulton, Ltd., Burslem.

FIG. 122.—Magnetic separator.

"strongly" magnetic minerals are greater than 0·001, "feebly" magnetic minerals between 0·001 and 0·0001.

A **Lifting separator** consists essentially of a magnet which can be passed amongst the material to be separated in such a manner that the magnetic particles adhere to the magnet and are removed along with it when the magnet is withdrawn from the material. This method is quite suitable for very small quantities of material, but it is too slow to be used for large quantities.



Wm. Boulton, Ltd., Burslem.

FIG. 123.—Magnetic separator.

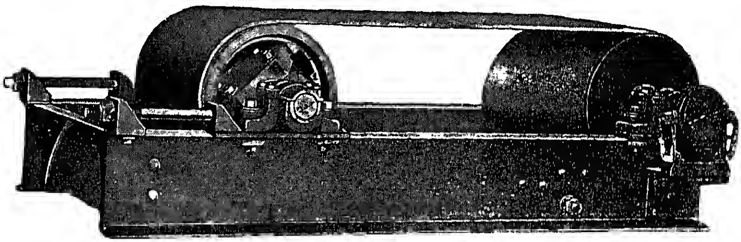
A **Retaining separator** usually consists of either

(*a*) A chute or inclined trough, in which are a number of magnets which retain certain of the particles passing down the trough whilst the remainder pass along and are separated. The apparatus must be stopped at intervals in order that the magnetic material may be removed from the magnets. Figs. 122 and 123 show an apparatus of this kind in which the magnets are in the form of a series of baffles across the trough, so as to disturb the water and secure an effective separation. For cleaning, the flow of material is stopped and the

electric current switched off. The magnetic particles can then be washed down with water and the apparatus started again in less than five minutes.

(*b*) A drum or pulley, formed of a series of magnets, which rotates whilst the material to be treated passes over it. The attracted particles adhere until the drum has reached a prearranged part of its revolution, when the electric current which creates the magnet is automatically shut off, and any adherent particles then fall away into a suitable receiver. As the drum continues to revolve the electric current is again applied automatically and the drum again becomes a magnet.. Instead of one magnet, a large drum with several magnets on its circumference may be used.

In some cases, instead of allowing the mixed materials to flow directly over the drum, they are carried on an endless belt, the magnetic drum serving as one of the pulleys, as in the Ingranic Separator (Fig. 124). This arrangement works in a similar manner



Sturtevant Engineering Co., Ltd., London.

FIG. 124.—Ingranic magnetic separator.

to the magnetic drum just described, but the use of a belt is sometimes more convenient. Another separator of this type is the Wetherill Separator (Fig. 125), which has three electro-magnets, one of which forms one of the pulleys supporting the belt upon which the material to be separated travels. The magnetic grains are carried round the pulley and fall into one receiver, whilst the non-magnetic particles shoot forward and fall into a second compartment.

Further classifying into strongly magnetic and weakly magnetic materials may be carried out by the use of two cylinders, the second having a higher speed or a weaker magnetic field. This method is employed in the "Monarch" separator, in which the material falls on to the first cylinder and is separated from the magnetic material. Just as the latter falls from this cylinder it is caught by the magnetising zone of the second cylinder, but only the strongly magnetic particles are able to be held, and so a further classification into strongly and weakly magnetic particles is effected. A machine of this kind with cylinders 2 ft. diameter, the first revolving at 40 revs. per min. and the second at 50 revs. per min., will separate 15-20 tons per hour of material between 15- and 20-mesh,

the power required being about 1-1½ h.p. for the magnets of each cylinder and ½-¾ h.p. for rotating the cylinders.

A similar separation may be effected by using a horizontal cylinder which revolves between the two poles of a fixed electro-magnet, these poles surrounding the greater part of the cylinder. The point of strongest attraction will be exactly on the centre line through the magnets, and the point of least attraction will be at the lowest point to which the material is carried by the revolving cylinder. Thus, the stronger the magnetic properties of the material the further will it be carried round, and so by arranging hoppers in suitable positions beneath the cylinder the material may be divided into several groups each of a different

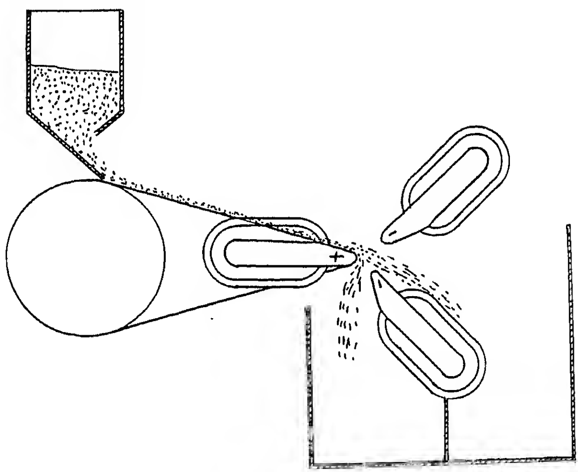


FIG. 125.—Wetherill separator.

magnetic intensity. This arrangement is adopted in the International Separator.

Deflecting separators are those in which some of the material is drawn aside by the magnets and so separated from the remainder. The simplest separator of this type consists of a narrow inclined table or trough, down the sides of which are fixed a series of magnets. As the material flows down the trough the readily magnetised particles are deflected and adhere to the magnets. Rotating drum magnets, such as those described on p. 430, are sometimes regarded as deflecting separators.

In all magnetic separators it is important (*a*) to use sufficiently strong magnets—preferably electro-magnets, as their intensity is under better control; (*b*) to allow the material to be separated to be in as close contact as possible with the magnets, as all intervening substances, such as belts, etc., reduce the efficiency of the

separation of the smaller particles; (c) to allow ample time for the desired material to reach and adhere to the magnets, and, in the case of rotating magnets, to allow the adherent material to be carried sufficiently far to ensure a complete separation. If a rotary electro-magnet is used, the construction of the commutators is important, as a quick "make and break" is essential.

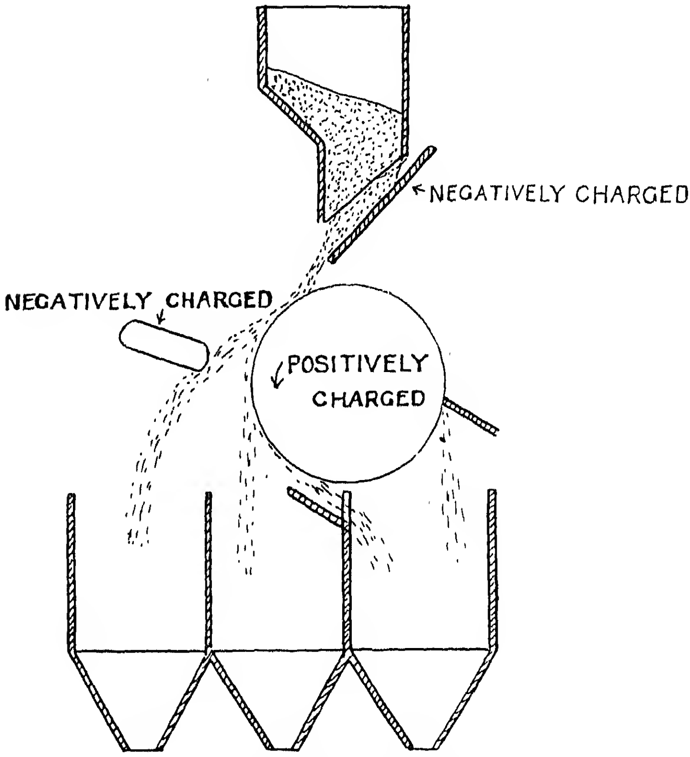


FIG. 126.—Electrostatic separator.

ELECTROSTATIC CONCENTRATORS

Electrostatic separators (Fig. 126) are sometimes used for concentrating dry materials. They depend on the fact that, if a stream of material is brought into contact with an electrically charged body, those particles in the stream which are good conductors of electricity will become similarly charged and repelled, whilst those which are poor conductors will continue their flow undisturbed. A still more definite separation will take place if

the whole of the material is first charged negatively and is then brought into contact with a positively charged body. There are various forms of electrostatic separators, but the essential features of all are that the material flows down an inclined chute which is negatively charged and then falls on to a positively charged revolving cylinder, at the side of which is a second negatively charged electrode. The particles, which are good conductors, are immediately repelled from the revolving cylinder, whilst those which are poorer conductors continue to adhere for a length of time depending on their conductivity. By this means it is relatively easy to separate a material into three different portions, viz. highly conductive, medium conductive, and feebly conductive. As different minerals vary in their electrical conductivity they may be separated in this way from one another. Thus, magnetite, magnetic ilmenite, magnetic haematite, pyrrhotite, chromite, ilmenite, haematite, wolframite, pyrites, columbite, tantalite, gold, etc., are highly conductive; ferriferous amphiboles and pyroxenes, black biotite, tourmaline, titanite, rutile, anatase, brookite, and cassiterite are medium conductors; and siderite, xenotime, epidote, olivine, staurolite, garnet, monazite, gypsum, quartz, chalcedony, felspars, calcite, dolomite, cordierite, muscovite, apatite, andalusite, sillimanite, fluorite, diamond, topaz, kyanite, spinel, corundum, celestite, zircon and barytes are poor conductors of electricity.

PURIFICATION BY CHEMICAL ACTION

The chemical treatment of sand is only used in special cases as it is expensive, and in most cases sand can be sufficiently well cleaned by other means.

Hydrochloric acid has been used to some extent for removing iron compounds from sands. It is useful in some cases, but is seldom completely satisfactory, partly because some iron compounds are unaffected by hydrochloric acid even when heated to high temperatures, and partly because the acid cannot penetrate to the interior of the particles, and so does not remove the wholly enclosed iron compounds; when the sand is used for any purpose, such as grinding or glass manufacture, in which the interior of the grains is eventually exposed, such enclosed iron compounds may then have a serious effect. For this reason, the treatment of sands with hydrochloric acid is only of value when the whole of the iron is in the form of an exterior coating on the particles.

Iron compounds may be removed from kieselguhr by mixing it with hydrochloric acid (specific gravity 1·1) to form a fluid-paste and then heating the mixture to 80° C. The mass is cooled, washed with water passed through a filter press, and the cakes dried and ignited.

Instead of being treated with hydrochloric acid, sands may be

mixed with common salt and heated to redness. This results in the formation of ferric chloride, which is volatile and so escapes. Unfortunately, salt is no more efficient than hydrochloric acid, but it is sometimes cheaper to use it.

Concentrated sulphuric acid is used for removing iron oxide from artificial carborundum sands, which are used for abrasive and refractory purposes.

Tscheuschner in 1885 recommended the removal of iron oxide (limonite) from sands by sprinkling 64 parts of sand with 8 parts of a solution of 3 parts of salt, and 2 parts of concentrated sulphuric acid and 3 parts of water. The mixture is heated to redness. The product is treated with water and the iron removed in solution as a chloride. J. G. A. Rhodin in 1914 patented a simplification of this process, which consists in heating the sand with 2½ per cent of common salt to a red heat, and afterwards lixiviating with water. Both Tscheuschner and Rhodin's processes are expensive, and are seldom used, as sufficiently pure natural sands can be obtained cheaply.

Nitre cake has been used quite satisfactorily for cleaning glass sands, and is also used for purifying artificial corundum sands. The same process may be carried out by using sodium hydrosulphide at a lower temperature.

Almost the only sands which are chemically purified on a large scale are those used for making optical glass, as the methods of purification are costly and can only be used in special cases.

CALCINATION OR BURNING OF SANDS AND SAND-ROCKS

Sandy materials are sometimes calcined in order to improve their quality, or for some special purpose in connection with their use. Thus, kieselguhr is sometimes calcined in order to burn off any carbonaceous matter which may be present, and to leave a white, or nearly white, kieselguhr.

Sandstones and silica rocks are sometimes calcined or burned in order to render crushing easier, and also (where they are to be used in the manufacture of silica bricks) to change the silica into tridymite and cristobalite (p. 226).

Glass sands are also improved by burning, as this treatment drives off any water present, as well as organic matter, and so improves the colour of the glass.

Dirt and coal may be included or mixed with sands during transport, but may be largely removed by careful burning. This is specially necessary in the case of sands for the manufacture of optical glass, as they need to be very pure.

Some sands become darker when burned; this is due to the oxidation of the iron present and the consequent production of the red colour characteristic of ferric oxide, or of the darker ferrous

silicate if the burning has been effected with an insufficient amount of air. Several British sands darken in this way, some pure white sands becoming grey or pinkish in colour, though the purest sands, such as the glass sands of Aylesbury, Godstone, and Reigate, remain pure white after burning, as do also selected portions of the sand from Muckish Mountain, Co. Donegal, Ireland, and that from Abergele. Glacial sands usually darken considerably when they are burned.

Some of the pure white sandstones of the Carboniferous age, such as that found at Guiseley, are unaffected in colour by burning.

The kilns employed for calcining sand and sand-rocks depend largely on the nature of the materials. In the case of sand-rocks, in which the pieces of material are comparatively large and hard, a **shaft kiln** may be employed. This type of kiln (Fig. 127) consists of an upright column or shaft into which the material is fed from above, and passes out at, or near, the ground level. The fuel for burning the material may be mixed with the stone—alternate layers of fuel and stone being placed in the kiln, or the fuel may be burned in a number of fireplaces or burners so that only the products of combustion pass into the kiln. The former method is seldom employed, the latter being much more satisfactory, especially if producer-gas is used as fuel, as there is practically no contamination of the sand by the ash from the fuel.

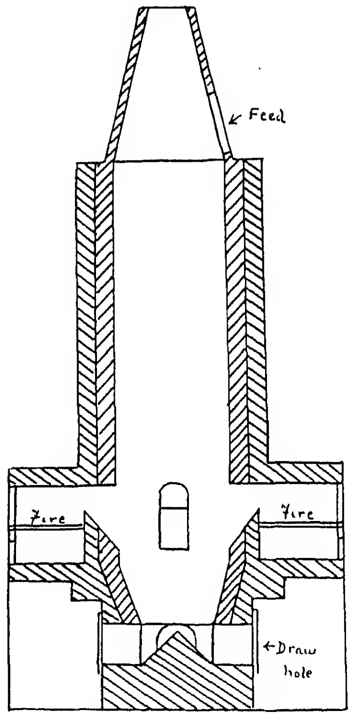


FIG. 127.—Shaft kiln.

Shaft kilns may be worked either intermittently or continuously; in the former, each filling of the kiln constitutes a separate operation, whilst in the latter, the materials may be continuously fed into and drawn from the kiln. Intermittent kilns are only employed for small outputs and are not usually built more than 10 ft. in diameter at the top, and 5 ft. at the bottom, and 20 ft. high. Continuous shaft kilns may be up to 60 ft. high, from the feed-hole at the top to the draw-hole near the bottom.

Whilst a shaft kiln is simple in construction and economical in fuel, if properly controlled, it has several disadvantages which may

be overcome to some extent by careful designing. The principal disadvantages are :

1. The kiln is liable to become choked, with the result that the firing is irregular. This can, to some extent, be avoided by blowing air through the material during the burning.
2. The heating may be irregular unless the fireman is both skilful and conscientious.
3. A shaft kiln is not suitable for material containing much powder, as it then chokes too easily.

Single-chamber kilns are sometimes employed for calcining blocks of material, such as sandstones, silica rocks, etc., which do not fall to powder when burned. A single kiln consists of a brickwork chamber round the base of which fireboxes are placed, so that

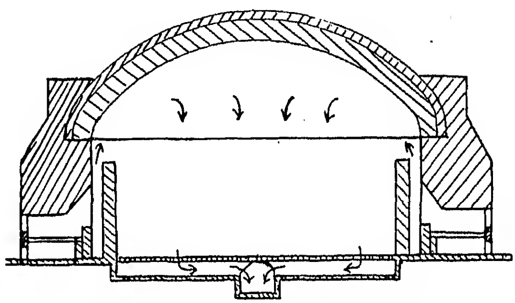


FIG. 128.—Section of down-draught kiln.

the products of combustion from the fuel enter the chamber, pass through the material stacked in the kiln, and escape to a chimney or are drawn out by means of a fan. Such kilns may be either circular or rectangular, and the gases may pass in either an upward or downward direction. The advantage of up-draught kilns is that they are very simple in design and are easily repaired, but they have the disadvantage of being wasteful in fuel, as the gases pass to the chimney before the heat in them has been fully utilised.

In down-draught kilns (Fig. 128), the gases from the fireboxes are first passed up to the top of the kiln, through vertical flues termed *bags*, and are then drawn down through the material in the kiln and out through a perforated floor into flues which are connected to a chimney or fan. In this type of kiln, the distance travelled by the gases is very great, and consequently the heat is more fully utilised than in an up-draught kiln. Down-draught kilns are, however, more complicated in construction, and consequently require more skill in use and maintenance.

In some rectangular single kilns, the fires are placed at one end and the chimney at the other, the gases then travelling chiefly in a

horizontal direction. Such kilns with a horizontal draught are frequently known as Newcastle kilns.

Continuous-chamber kilns are sometimes employed for the same purposes as single kilns, but they have the advantage of utilising the heat in the gases more fully and so are cheaper to operate. A continuous kiln consists of a number of single kilns either of the up-draught or down-draught type, and, in some cases, of the horizontal draught type, connected together, so that the waste gases from one kiln or chamber, instead of passing to the chimney, are discharged into the next chamber, and then into the next, and so on, until the heat in them is fully utilised, when the gases are allowed to pass into the chimney and escape. By building several chambers or kilns together in this way the cost of building is considerably reduced, and the fuel consumption is less than half that of each separate kiln.

The difficulty of choking is also present in this type of kiln, and

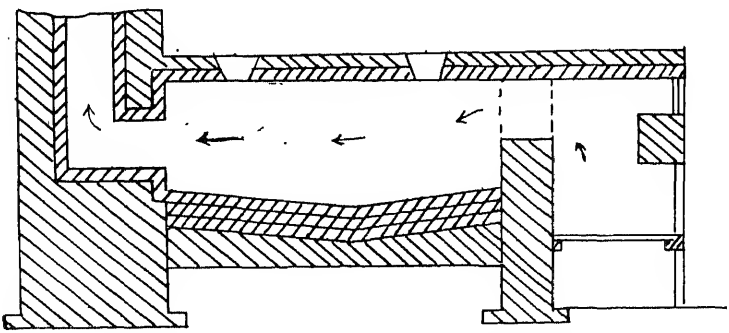


FIG. 129.—Section of gas-fired reverberatory furnace.

materials which are likely to fall on burning should not be fired in them. Continuous kilns are only suitable for outputs of 30-40 tons of rock per day.

Reverberatory furnaces (Fig. 129) are used for calcining metalliferous sands, chiefly in order to extract from them any metal they contain. A reverberatory furnace consists of a long hearth in which the material to be heated is placed; at one end of the furnace is a firebox and at the other a chimney. The products of combustion from the firebox pass over the material on the hearth, heating it in their passage, and finally passing away through the chimney at the opposite end. The arch of the furnace is built so as to reflect the heat down on to the material and so secure effective and uniform heating. In some cases, the hearth is heated from below as well as from above; this method effects a saving in fuel.

Roasting furnaces are used for treating metalliferous sands chiefly as a preliminary to the recovery of any metal they contain. In the hand-operated type, the furnaces consist of a number of

floors arranged one above the other with holes, each floor communicating with the floor below; the material placed on the floors is raked from one floor to another by hand, whilst the gases travel in the reverse direction and heat the material in their passage. This type of furnace is only suitable for materials which are in the state of a coarse powder.

Mechanical roasting furnaces are used in the treatment of metalliferous sands. A typical mechanical furnace consists of a series of either horizontal or slightly inclined floors, one above the other; the floors are perforated so that hot gases may pass upwards, through, and over the various floors and out at the top. In the centre of the furnace is a vertical air-cooled shaft which carries a number of horizontal arms fitted with rakes which stir up the material on the floors. These arms may, if necessary, be water-cooled. The material to be heated is charged on to the top floor; it is stirred by the rakes and gradually falls from floor to floor until it is discharged at the bottom, the gases meanwhile passing

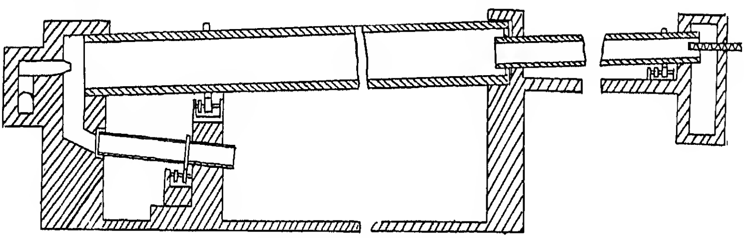


FIG. 130.—Rotary kiln.

upwards and heating the material in its passage. The chief advantage of this type of kiln is in its simplicity; it requires little skill in operation and is cheap to work, but has the disadvantage of high initial cost and requires mechanical power to operate the rakes.

Rotary kilns (Fig. 130) are only used to a very limited extent for calcining sands, though, where they can be economically employed, they are probably the most satisfactory kilns to use. A rotary kiln consists essentially of a steel cylinder or drum lined with fire-bricks or other refractory materials; the drum is slowly rotated about an axis slightly inclined to the horizontal. The material to be heated is fed in at the upper end of the kiln, and the fuel and air are injected at the lower end. The material gradually passes along the drum, being agitated during its passage by the rotation of the drum, and sometimes by baffles in the latter, and is finally discharged at the opposite end of the kiln. The cylinder may be of any desired length, according to the amount of heating necessary, but is not usually economical when less than 100 ft. long and 6-9 ft. diameter. It may be lined with any suitable refractory material, the most satisfactory being one containing

about equal proportions of silica and alumina, made of a mixture of fireclay and bauxite. The kiln is usually supported on two or three pairs of roller-bearings, placed at a convenient distance apart; and is driven by a toothed wheel surrounding the cylinder and actuated by a worm wheel driven by means of a suitable reduction gearing. The speed of rotation varies from 20-60 revs. per hour.

The fuel generally used for such rotary kilns is a fine bituminous coal-dust, though natural gas, producer-gas, and petroleum are used to some extent. The coal is thoroughly dried and ground so as to leave only about 15 per cent on a sieve having 180 meshes per linear inch. The powdered coal is conveyed to hoppers and is introduced into the kiln at a regular speed. A blast of hot air drives it into the kiln and ensures its rapid combustion. As the coal is very finely divided it is completely burnt, and does not injure the material which is being heated, except in so far as contamination of the latter by fuel-ash is harmful.

At the discharge end of the kiln, a cooler, which usually consists of an inclined rotating drum, is fitted to cool the material before it is discharged ; if desired, water may be used to sprinkle on the material and so cool it more rapidly.

Rotary kilns are quite continuous and very economical in fuel and labour. They can only be used, however, where a very large output is required, as rotary kilns with small outputs are not economical. The cost of installation is very high, and this also necessitates a large output. Unlike the other kilns mentioned, rotary kilns are only suitable for powdered materials ; large pieces are imperfectly burned.

The calcination or burning of sands and sand-rocks may be carried out in either an oxidising or reducing atmosphere, according to local requirements. Sand-rocks such as sandstones, quartzites, etc., which are heated to convert them into tridymite and cristobalite, or which are heated to render them easier to crush, also glass sands, kieselguhr, etc., are calcined in an ordinary oxidising atmosphere. Metalliferous sands may, in some cases, be heated in an oxidising atmosphere, but in others a reducing flame is necessary ; the particular conditions must be adapted to the needs of the material being heated.

The temperature and duration of heating depends on the purpose of the calcination. Where a sandstone is calcined to render crushing easier, a temperature of 900°-1000° C. is all that is necessary, but where it is desired to convert silica into tridymite and cristobalite, a much higher temperature—about 1400° C.—is required, and the heating must be continued for a very long time, whereas in the first case it is merely necessary to heat up and then cool quickly, if necessary by quenching the material in water. Where it is merely desired to drive off any carbonaceous matter which may be present, a temperature of 900°-1000° C. is generally sufficient, provided an ample supply of air is passed through the kiln.

For roasting metalliferous sands, the temperature depends on the nature of the metal and the change which it is desired the heating should effect. When the metallic compounds are to be reduced and the crude metal extracted from the sands, a highly reducing atmosphere is essential, and usually the sand must be mixed with coke, charcoal, or other reducing agent, prior to its entering the furnace. A shaft kiln (known in this case as a "blast furnace") or reverberatory furnace is usually employed for this purpose, the molten metal being run off through a tap-hole in the side of the furnace. It is not usually economical to treat crude sands in this manner; the desirable mineral in them is usually separated by a process of concentration, and the rich ore so produced may then be smelted by one of the processes ordinarily used for rich materials.

CHAPTER X

SIZING OR GRADING SANDS

SIZING or grading is the process of dividing a sand into particles of various sizes. It should seldom be omitted, no matter what may be the purpose for which a sand is to be used, though in some cases a partial grading is sufficient. In the most primitive cases, grading is used to separate small grains of sand from pebbles, gravel, flints, or from other relatively large pieces of undesirable matter. In other works, it is used as a means of separating grains of desired sizes from the rest. In the case of placer sands, which contain particles of valuable metals or ores, sizing is necessary in order that the classifiers may work to the best advantage.

A perfectly graded sand will contain no grains larger or smaller than those specified, but perfect grading is seldom attained and would, in most cases, be prohibitive as regards cost. Consequently, the grading is usually effected within fairly wide limits, the selected grades depending on the particular purpose for which the sand is to be used. A very convenient series of grades, used for many years by the author, is shown on p. 249.

A series of grades proposed by Boswell is shown on p. 211, that proposed by F. W. Taylor is shown on p. 248, whilst other series of grades have been proposed by Seger (p. 211) and Mellor (p. 211). Unfortunately there is no generally accepted standard series of grades, but if wherever possible the I.M.M. standard sieves (p. 247) were used, the need for a standard grading figures would be less marked. Accurate standard screens are by no means necessary for use on a large scale, but the product from the screens actually employed should be tested with standard sieves from time to time so as to ensure its general conformity to requirements. The use of standard sieves for this purpose has been described on p. 246.

The separation of the sand into particles of various sizes may be made with either wet or dry sand according to convenience. Where the material has to be washed as well as sifted, it is usually easier to sift it in the wet state, but sands which are merely damp, yet do not require to be washed, should usually be dried before being graded.

Sizing or grading may be effeeted by three principal methods, namely :

(a) Screening or sifting the wet or dry material.
(b) Water grading.
(c) Air separation.

The first mentioned is generally used for the comparatively coarse grains, whilst the last two are used for the finer grains which cannot be conveniently separated by sieves or screens.

SCREENING OR SIFTING

Screening or sifting is the process usually employed for separating into different sizes all sands with particles coarser than 0·0025 in. diameter. Grains which are finer than this cannot be conveniently sieved but must be classified by means of either water or air.

Screens or sieves are of various kinds, the principal ones being :

(1) *Fixed screens,* which may be (a) flat, (b) conical, or (c) cylindrical.
(2) *Movable screens,* which may be (a) reciprocating, (b) rotary, or (c) sieve-conveyors.

The terms used to describe screens are rather loosely applied. *Riddles* are very coarse screens. A *sieve* or *screen* may be regarded as a riddle having moderately fine openings, whilst a *lawn* is a very fine screen, having 100 to about 350 holes per linear inch. These terms are not standardised, however, and the term "sieve" may be applied to a "lawn," whilst the term "screen" is often used for a "riddle," and *vice versa.*

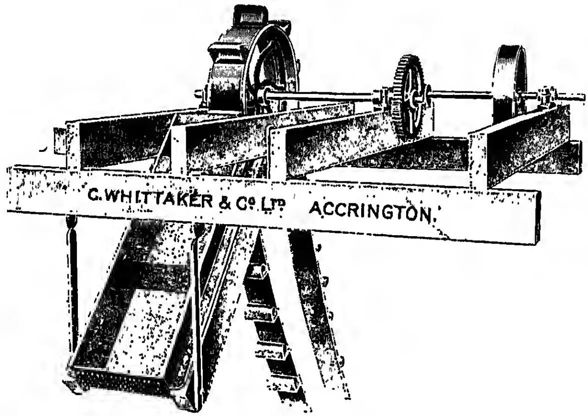
Fixed flat screens consist, usually, of a flat surface, or sheet composed either of a meshwork of wires, a number of straight wires (Fig. 131) forming long slots, or a perforated or slotted metal plate. The term "flat screen" is used even when the screening surface is inclined, so that the material supplied to it may travel down the incline and so enable the screen to work continuously. Perfectly flat screens are only used on a comparatively small scale; they must be emptied periodically, or they will become filled with coarse material which will not pass through their apertures.

When the screen or sieve is horizontal it may be held in the hand, or more conveniently, it may be supported on two strong bars. A suitable quantity of the sand is then placed in the sieve and the latter is shaken or moved backwards and forwards so as to aid the smaller particles in passing through it. Sometimes it is more convenient to keep the sieve stationary and to rub its contents gently until all the particles which can do so have passed through the sieve. Such sieves are only suitable for a small output, and their use is often tedious.

When an inclined screen or sieve is used, the crushed stone or

sand is supplied to the upper end of it in a uniform manner across the whole width of the screen and slides down it, the finer particles passing through the meshes or perforations of the sieve whilst the coarse particles which will not pass through fall off at the lower end as "tailings." The screen must, of course, be of sufficient length (or a series of screens must be used) to ensure that all the smaller particles are separated. Many inclined screens are too short and too steeply inclined to do their work properly, with the result that a very imperfect separation is effected.

It must be clearly understood that with an inclined screen the largest particles passing through it will not correspond to the mesh or perforations of the screen, but will be the "projection" of such apertures on to a horizontal plane. Thus, if the screen



C. Whittaker & Co., Ltd., Accrington.

FIG. 131.—Piano-wire screen (see p. 446).

were a sheet of steel, with holes $\frac{1}{8}$ in. diameter, inclined at an angle of 45 degrees, the effective size of its perforations would be 0·0875 in. or about three-quarters of the apparent aperture. Owing, however, to the rate at which the particles slide over a sheet of smooth metal inclined at such an angle, most of the particles will be less than $\frac{1}{24}$ in. diameter. Hence, the actual size of the particles separated can only be found by trial, as it depends on the inclination of the sieve and the speed at which the material travels over its surface. In order to prevent the material from passing too rapidly over the sieve, it is sometimes desirable to make the sieve in two or more parts—one sloping at a fairly steep angle and the others at a smaller angle. By doing this, the speed of the material is lessened by the baffling action of the later slopes. The same effect may sometimes be obtained by arranging small baffles across the surface of the sieve, which arrest the speed of the material to some extent, and so render the screening more efficient.

The efficiency of a flat or inclined sieve also depends on the kind of material to be screened. Where this contains a large variety of sizes, it is more difficult to obtain a good separation, as the smaller particles become mixed with the larger ones and are not sufficiently separated in the short time during which the material passes over the screen. When most of the particles are of a size which will pass through the screen and only a small proportion are larger, the separation is much more efficient.

Coarse material may be more efficiently screened than fine, as the holes, being larger, are less likely to become clogged. The kind of apertures employed is also very important; they may be formed by either (*a*) wire gauze, (*b*) parallel wires, or (*c*) as perforations in a plate of steel or other material.

Gauze or mesh-cloth is not usually satisfactory for a fixed sieve, unless some means is employed for vibrating it so as to prevent the clogging of the holes. When a suitable vibrating arrangement is provided, gauze is very satisfactory for comparatively fine particles. It is unsuitable for very coarse screening on account of its lack of strength. Gauze sieves are designated by numbers which, in this country, state the number of apertures per linear inch. Thus, a No. 24 sieve has 24 holes per linear inch, or 576 holes per sq. in. On the Continent it is more usual to specify the number of holes per sq. cm. Such Continental designations may be converted into the corresponding numbers by multiplying the square root of the Continental figure by $2\frac{1}{2}$. Thus, a Continental sieve designated as 4900-mesh, *i.e.* having 4900 holes per sq. cm., will correspond to $70 \times 2\frac{1}{2}$, or 175 in the English standard, and will be equivalent to a No. 175 English sieve. Conversely, an English No. 25 sieve would correspond to $(25 \div 2\frac{1}{2})^2$ or to a No. 100 Continental sieve.

Some Continental manufacturers designate their sieves by numbers which correspond roughly but not accurately to the English ones.

Table LXXIV. gives various figures which may be used in comparing sieves designated in different ways.

TABLE LXXIV.—NUMBERS AND MESHES OF SIEVES

Sieve No.	Meshes per Linear Inch.	Meshes per Sq. In.	Meshes per Cm.	Meshes per Sq. Cm.
30	30	900	12	144
60	60	3,600	24	576
90	90	8,100	36	1296
100	100	10,100	40	1600
120	120	14,400	48	2304
150	150	22,500	60	3600
200	200	40,000	80	6400

A difficulty experienced in connection with sieves designated in

one of the afore-mentioned ways is that it is not possible to tell what sized apertures they contain, as this depends on the thickness of the wires used. To overcome this, a series of standard sieves have been prepared by the Institute of Mining and Metallurgy in which all the apertures are the same diameter as the wires. In the United States a different standard is, unfortunately, used, and tends to cause confusion when British and American results are compared. The English Standard sieves and screens are shown in Table L. on p. 247.

When gauze or silk is used, the wires or threads tend to stretch and to sag, and are liable to be forced apart, thus allowing larger particles to pass between them. It is, therefore, important that the size of the particles passing the sieve should be tested periodically so as to ensure that the sieve is in proper working order. When larger particles are found, the mesh of the sieve should be carefully examined, and the defect repaired. The gauze may be made of iron, steel, brass, bronze, or less frequently copper. "Lawns" are usually made of silk; they are too delicate to be used on a very large scale. The non-ferrous metals may be used for very fine screens and where it is desired to avoid contamination by iron. Phosphor-bronze is largely used for the finer sieves, on account of its hardness and toughness.

Small sieves may be made in one piece, but larger ones are usually in sections, each mounted on a suitable frame and fixed into the screen framework. By dividing the gauze into sections repairs are facilitated, no unnecessary waste of gauze occurs, and replacements can readily be made. If the screens are properly designed a defective piece should be removed and replaced by a sound one in the course of two or three minutes. This is very important, as it reduces the time lost by the stoppage of the apparatus to a minimum.

Another reason for using moderately small frames is that unless the gauze is tight it is impossible to vibrate it properly, and tight gauze cannot be obtained in a large frame owing to the tendency of the cloth to sag. Screen frames measuring 6 ft. by 4 ft. are about the maximum size which gives the most convenient handling with ease of replacement and low cost of repairs. It is also desirable that the frames should be sufficiently small to enable the required tension in the gauze to be obtained without straining it, because it is very important that the screening surface should be taut so as to give a good separation; 40 per cent or more of the fine material may be left in the tailings through a screen not being sufficiently taut. As the wire is certain to stretch in use, some means should be provided for tightening the gauze from time to time.

For further information see p. 448.

Parallel bars and wires are used for screens or riddles where the particles are globular or free from flakes or long thin pieces. "Grids" or gratings composed of a series of parallel bars with a

definite space between them are excellent for separating pebbles and other coarse particles, but they are seldom efficient if the spaees between the bars are less than $\frac{1}{8}$ in. wide. The largest grids are often known as "grizzlies," and they are chiefly used to separate small stones or gravel from sand, or the small pieces of rock from that which requires to be crushed. Being very strong, they are not damaged by tipping a wagon- or truck-load of material on to them, so they form an effective feeding device for other machines.

Bar-riddles or grids may be either horizontal or sloping according to the conditions under which they are used. If sloping, the inclination should be slight—seldom exceeding 30 degrees, or the material will pass along too rapidly for it to be properly screened, though for damp sand an almost vertical riddle is often used, the material being thrown against it with considerable force.

The bars may be made of iron, steel, or wood. They may be round, square, rectangular, or triangular in section, the last-named being best as regards preventing the particles becoming fixed between the bars, but not as durable as square or rectangular bars. Round bars are objectionable, as they are closer together at their diameter than on the surface of the grid, and thus tend to cause an excessive proportion of wedged pieces, which are often difficult to remove.

The bars may be of any convenient length. Such grids are often 8 or 12 ft. long and usually about 4 ft. wide, though there is really no limit to either their length or width, as they can be built in sections to ensure the requisite strength.

For separating particles less than $\frac{1}{8}$-in. diameter parallel wires are preferable to bars. If such wires are fixed without any appreciable tension, they are satisfactory for light work and for hand-riddling, but not for continuous work. For the latter, the wires should be stretched by tension keys, as in a pianoforte: hence the term "piano-wire" screens. Parallel wires, arranged along the length of the sieve and sometimes strengthened by a few cross wires, sieve more rapidly and readily than gauze sieves. They have the disadvantage that if a long thin particle falls on to the screen it may pass between the wires, whereas it could not pass through a gauze screen of the same mesh, as the cross wires would stop it. This, however, does not often happen in screening a material such as sand and crushed rock, as the particles are in most cases fairly cubical. A further difficulty encountered with screens having only parallel wires is that a large particle may force the wires apart and then allow other larger particles to pass through the opening so created. This defect cannot be wholly avoided, but it can be minimised by keeping the wires taut, so as to allow as little movement as possible, and by inspecting the screen frequently; it does not occur with gauze screens.

Screens with parallel wires and no cross ones have a tendency to cause the material to race too rapidly over them and thus prevent an efficient separation of the particles. This may be minimised by

reducing the inclination or slope of the screen or by arranging the wires across the screen instead of longitudinally, thus retarding the flow of the materials and so effecting a sharper separation. Screens composed of parallel wires set closely together should usually be provided with some means of vibrating the wires sufficiently to keep them clean. If the wires are stretched taut the movement of the particles may cause the requisite vibrations; otherwise they may have to be produced mechanically.

Although piano-wire screens have obvious advantages over those made of gauze, the risks involved in their use are sufficiently important to make many managers prefer gauze screens. The lower output of a gauze screen may easily be overcome by providing a larger screen area, but a badly screened product containing particles too large in size may easily cause serious financial loss to a firm.

Perforated steel plates are the most convenient form of screen where particles between $\frac{1}{25}$ in. and 2 in. are to be separated. Still larger perforations can be made, but the wear and tear are so great that it is cheaper to pass such coarse material over a grid or grizzly. The shape and size of the perforations varies according to circumstances. Sometimes the plate is corrugated as well as perforated, or several plates may be arranged in steps. Slots have the advantage over circular perforations of offering a larger screening surface per square yard of sheet, but are very liable to pass long flaky pieces which would be rejected by round holes. Consequently, it is usually better to employ the latter, though this may involve the use of a larger screen to produce the same area of apertures.

Inclined perforated or slotted plates are so smooth that the material tends to race over the surface, with the result that some of the material fails to pass through the holes, and this must be allowed for in purchasing screens of this character. It is also very important that the angle at which the screens are placed should be very carefully adjusted so as to allow for its effect on the sand and on the rate at which the latter travels over the surface. Baffles, or the use of two or more screens at different angles, may be necessary to retard an excessive flow of material.

The thickness or "gauge" of the metal used for slotted and perforated screens should be sufficient to give ample strength. Those in Table LXXV. make reasonably durable screens; thinner sheets should not be used except under special circumstances.

It has previously been pointed out (p. 443) that the largest particles which pass through the openings in an inclined, perforated sheet are much less than the openings themselves. This is due to the slope at which the screen is hung and must be duly allowed for in purchasing a screen. It is often an advantage to hang the sheet from four chains, by a hook at each corner of the screen; this enables the inclination of the screen to be adjusted rapidly and easily so as to suit any variation in the material.

TABLE LXXV.—PERFORATED SHEETS

Diameter of Hole.		Thickness of Sheet.		Centre to Centre of Perforation.	
Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
3/32	0·094	3/80	0·037	5/32	0·156
7/64	0·109	1/20	0·050	3/16	0·187
1/8	0·125	1/16	0·062	3/16	0·187
5/32	0·156	5/64	0·078	1/4	0·250
3/16	0·187	7/64	0·109	19/64	0·297
1/4	0·250	9/64	0·140	3/8	0·375
5/16	0·312	11/64	0·172	7/16	0·437
11/32	0·344	3/16	0·187	15/32	0·468
3/8	0·375	1/4	0·250	1/2	0·500
1/2	0·500	5/16	0·312	11/16	0·688
5/8	0·625	3/8	0·375	13/16	0·812
3/4	0·750	5/8	0·625	1 1/8	1·125
1 to 4	..	3/4	0·750	..	..

NOTE.—With holes 1-4-in. diameter the total area of the holes should not exceed 43 per cent of the total area of the sheet, and preferably should not exceed 36 per cent, or the sheets will probably be too weak to be durable. If the diameter of the holes is not the same on both sides of the sheet, that on the lower side should be slightly the greater, so as to prevent the material from wedging in the holes.

The Relative Efficiency of Horizontal and Inclined Screens.—The efficiency of a fixed horizontal or inclined screen depends on several factors, of which the most important are :

(i.) *Its length* ; many users employ screens which are far too short to ensure a good separation of the coarse and fine materials. This can best be ascertained by testing the tailings with a hand-sieve of the same apertures. In most cases, a length of not less than 6 ft. is necessary, though 4 ft. is more usual. Where several screens are employed in series at different angles, each should be at least 4 ft. long.

(ii.) The *inclination* or *slope*, which must vary according to the type of screen used, though an angle of 45 degrees is generally satisfactory. If the screen is vibrated, an angle of 30 degrees with the horizontal will usually suffice.

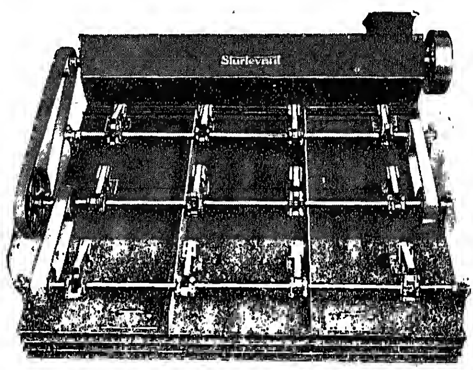
(iii.) *Smoothness of Surface.*—A perforated sheet or a screen composed only of parallel wires will oppose less resistance to the flow of the material than one with cross wires, and so will tend to retain in the tailings a larger proportion of fine material than will a gauze screen. This may usually be overcome by using a longer screen. The output of a gauze screen is often low because of the resistance caused by the cross wires, though this may be largely overcome by vibrating the screening surface.

(iv.) *Distribution of material on the screen* ; thus, if the material is spread uniformly across the whole width of the screen and continues to be so distributed throughout its journey, the efficiency of the screen will be high. Many users feed the screens carelessly, with the result that a large proportion of the available surface is

not used at all. Uniformity of distribution is secured in the "Newaygo" screen (Sturtevant Engineering Co., Ltd., London) by means of a screw conveyor which discharges material over a weir on to the screen. In other screens baffles are used.

(v.) *The nature of the material.*—Some materials are much more easily screened than others as the proportion of material to be removed often exerts a notable influence on the process. Thus, it is extremely difficult to remove completely a small proportion of moderately fine material from a coarser one and damp material is more difficult to deal with than a dry one.

(vi.) *The vibratory movement of the screen.*—The greatest efficiency is obtained from a gauze sieve or lawn when the particles of sand, etc., are in a rapid state of motion in an almost vertical direction. They should rise sufficiently above the gauze to drop



Sturtevant Engineering Co., Ltd., London.

Fig. 132.—Newaygo screen.

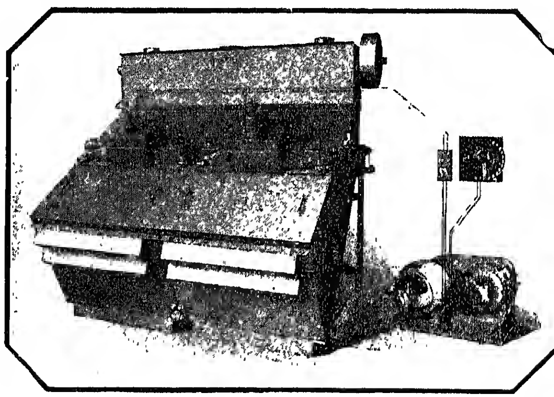
on an aperture which is not already occupied and, in the case of an inclined screen, should gradually pass down the incline in a series of small "hops" over each succeeding cross-wire. With fixed screens, the usual method of effecting this movement is to vibrate or rap the screen.

The simplest form of vibrator consists of a series of short bars which are attached loosely to a series of rotating discs, so that these bars strike on small anvils on the frame of the screen in rapid succession. The greater part of the vibration is absorbed by the frame, but sufficient movement is transmitted to the screening surface to ensure a reasonably high output. This method is noisy, destructive, and not very efficient.

A great improvement on it is incorporated in the Newaygo screen (Fig. 132) in which a series of strips of metal are placed at regular intervals on each side of the gauze; attached to these strips are a number of metal holders which project through the

sing of the screen and carry wooden pegs which act as hen struck at frequent intervals by a number of loose bars attached to a series of rotating shafts fitted above using. In this way, the screen is vibrated by blows delivered st directly to many points on the surface at a fairly rapid and clogging is effectually prevented. The hammers and ....ils should be arranged so as to give only a very small amplitude of motion to the screen, not enough to cause violent movement of the material, yet sufficient to free the particles and to present them with ample opportunities of escaping through the openings. Two screens, one below the other, may be vibrated simultaneously, but in that case the upper sieve must not be finer than about 15-mesh.

What appears to be a still more effective method consists of



W. S. Tyler Co., Cleveland, U.S.A.

FIG. 133.—Hum-mer screen.

several powerful electro-magnets mounted above the gauze (Fig. 133) which alternately attract and release strips of steel attached to the screening surface at a very rapid rate, in a manner precisely similar to the vibrations of the hammer in an electric bell, and keep the gauze in a state of constant vibration. The makers of this "Hum-mer screen" claim that the intensity of vibration is far greater and more effective than with hammers, that it can be varied at will in order to suit the material to be screened, and that very little power is required. By applying an intensely rapid vibration direct to the gauze, the particles are constantly separated from each other, the larger ones helping the smaller particles to pass more readily through the screen, and enabling the screen to have a very large capacity and a very sharp separation. Rapid vibrations of small amplitude also prevent the material jumping or bouncing on the screen and enables a smaller angle of inclination to be used and a sharper separation to be effected.

Whenever a vibratory mechanism is used, the screen should be fully enclosed in a dust-proof case, or the loss of the finest material will be serious.

Testing Tailings.—When a sieve or screen works perfectly, all the particles up to a certain desired size pass through it and the tailings will not contain any particles less than this size. Consequently, if the tailings were passed a second time over the sieve, no further material would be separated. It is practically impossible to secure so perfect a result on a large scale, as no sieve in the market has a 100 per cent efficiency. The only way to obtain the best possible result is to investigate several types of sieves or screens, vary their inclination, length, and mode of feeding, and to test the tailings with a hand-sieve of the same mesh or aperture. It is also a wise precaution to make periodically similar hand-tests of both tailings and screened material, so as to ensure a "clean" product, during the regular working of the plant.

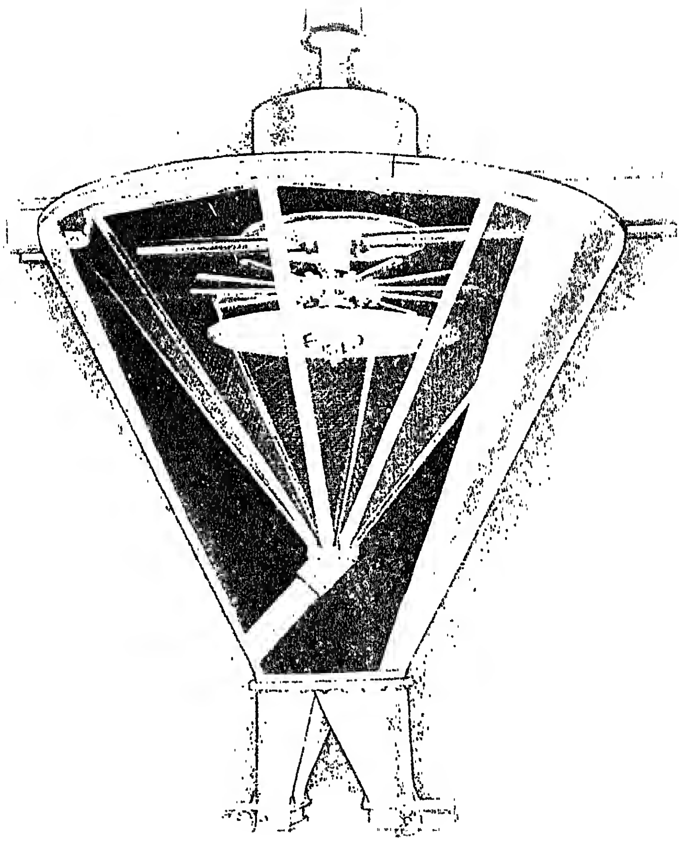
Supports for Screens.—Horizontal and inclined screens are often used for hand-sifting; a flat screen is usually placed on an open support, such as a pair of rails, or on top of a tub, box, or bin, and half-filled with the material to be sifted. The screen is then moved backwards and forwards on its supports, or is lifted in the hands and shaken horizontally until it is judged that the whole of the fine material has been removed. With care, a highly efficient separation may be effected.

An inclined screen or riddle may be set up at about 75 degrees or other suitable angle and the material is thrown against it; the finer particles pass through, whilst the tailings fall down to the bottom of the screening surface. The efficiency is low, but often sufficiently good for the purpose, especially when the rejected material is rather coarse. An ordinary labourer kept supplied with material, and working ten hours a day, will screen 24 cu. yds. of sand and gravel in this way. For larger outputs, it is cheaper to support the inclined screen above the ground, at a slope of 45 degrees or less, and to feed the material on to the upper end of the screen, so that it slides down the surface, the smaller particles passing through the screen and being separated in this way. Inclined screens are made to screen 15-20 tons per hour of sand of 20-mesh or 10-15 tons per hour of sand of 40-mesh. The supports may be of timber or iron, the latter being preferable as it is stronger and more durable. Chains (p. 447) are sometimes preferable to more rigid supports.

Fixed Conical Screens.—Conical screens are sometimes used because their shape permits a larger screening area to be employed within the same floor space as a horizontal or inclined screen. They also facilitate the delivery of the sand, etc., through a small spout, though, to be effective, the material must be arranged to flow uniformly over the surface of the screen. This is usually accomplished by means of adjustable baffles which guide the material, but in the conical screen made by the Traylor Engineering

Co., Allentown, Pa., U.S.A., the upper surface is swept by revolving scrapers which gradually move the particles from the rim to the centre of the screen, until they escape through an aperture in the centre of the cone, and are carried away as tailings.

A similar form of conical screen, made in this country, is the



Bickle Engineering Co., Ltd., Plymouth.

Fig. 134.—The Pulver Blender.

"Pulver Blender" (Fig. 134). Inside the cone is a rotary spreader plate above which a number of beaters are mounted. The screen is surrounded by a conical casing with an exit pipe in the base. The material to be screened is fed on to the rotary spreader plate and broken up by the beaters; the particles are then flung by centrifugal action on to the screen, the small ones passing through

the screen, whilst the larger particles pass down it and escape by the appropriate outlet.

The Vicona screen (Vol. II., Fig. 10; C. E. V. Hall, Sheffield) consists of a conical screen mounted above a similar, but inverted, screen, both being mounted in such a manner that they can be oscillated and vibrated, by means of a shaft and cam. The material is fed through a hopper on to the upper conical screen; the small particles pass through it and fall on to a second inverted conical screen, which may be either the same or a smaller mesh. In the former case, the material is separated into three different sizes each passing into a different chute. The coarse material, rejected by the first sieve, passes down the inside of the casing to the tailings chute; the material which has passed through the first sieve, but is rejected by the second one, passes down an inner casing into the "medium" chute and the material which has passed through the second sieve enters the "fines" chute. This type of sieve is very compact, yet has a specially large screening surface, and is very effective for all materials between $\frac{1}{4}$ in. and 200-mesh.

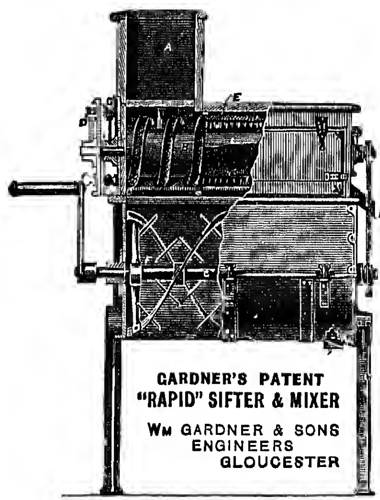


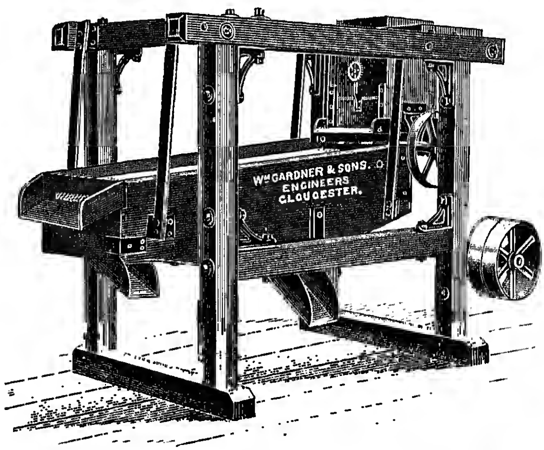
FIG. 135.—"Rapid" sifter.

Fixed Cylindrical Screens are sometimes employed. They consist of a cylinder made of gauze or perforated plate mounted in an almost horizontal position (Fig. 135); the material is introduced at one end, and is swept gradually through the cylinder by a cylindrical or spiral brush mounted on a shaft which passes through the centre of the cylinder. The brush presses the material against the surface of the screen, and also gradually carries it along through the cylinder. Sometimes the brush is replaced by paddles or scrapers which are intended to serve the same purposes, but are less effective. Occasionally, a half-cylinder forming a trough is used in connection with a brush, but the disadvantage of this arrangement is that it is less effective than when a complete cylinder is used. It is claimed that less power is required to propel the material through the screen by brushes or paddles than to vibrate the screen, but as against this the brushes wear away rapidly and are expensive, besides introducing bristles into the screened product, whilst with the finer screens the brushing causes a large amount of wear and tear on the screening surface.

Moving Screens or Sieves include those having three kinds of motion : (*a*) reciprocating, (*b*) jigging, and (*c*) rotary.

Reciprocating Screens.—The simplest form of reciprocating screen is an ordinary flat sieve which is shaken to and fro by hand. This method is very tiring, and is so slow that it can only be used for the smallest outputs. For larger quantities, some form of mechanical power must be employed to create the motion.

Power-driven reciprocating screens are usually of the flat type, one of the commonest patterns consisting of a horizontal screen or sieve (Fig. 136) moved to and fro along rails or guides by means of a bar having one end attached to the sieve and the other to the



W. Gardner & Sons, Ltd., Gloucester.

FIG. 136.—Reciprocating screen.

edge of a disc mounted on a shaft, so as to form a crank. It is sometimes more convenient, instead of using guides, to suspend the screen from the roof or from a framework, the motion being imparted in the same manner as before.

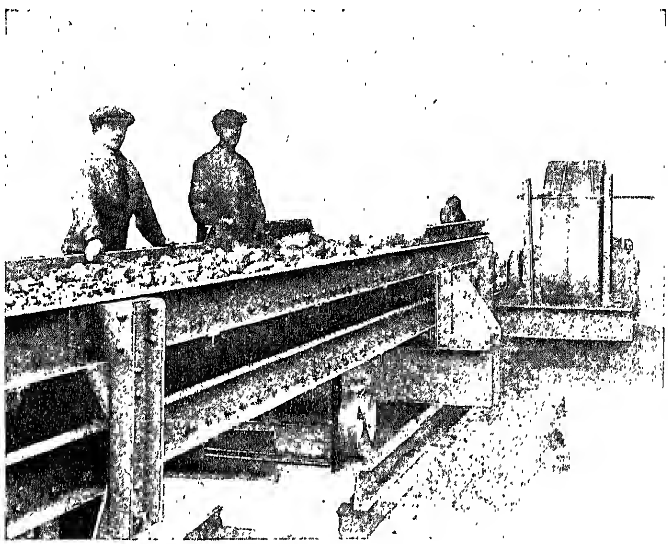
If desired, several sieves may be placed one above the other and reciprocated by a series of cranks. The finer particles from the upper sieves fall on to those below until they pass out into a suitable receiver. Such sieves must be emptied by hand unless they are made continuously acting by sloping them slightly and providing them with chutes. This method is sometimes used for washing and screening sand simultaneously (p. 400).

Reciprocating sieves of this type may be of any convenient size. They are usually moved at the rate of 30-70 strokes per min., according to the nature of the material. The output of reciprocating sieves is rather smaller than that of rotary sieves (described later), but for many purposes they are useful if kept in good condition. The wear and tear on them is rather great on account of the

reciprocating movement and unless well enclosed they are very dusty. When the sieves are used for washing (p. 399) the dust is, of course, avoided.

It is very important to avoid wasting power by the use of an unnecessarily violent reciprocal movement. All that is needed is to cause the particles to jump upward from the screen, which then travels forward and backward, so that the particles when falling do not strike the same aperture as that from which they rose.

Jigging Screens are a simple modification of the well-known jigging conveyor, which consists of a long shallow tray (Fig. 59)



Head, Wrightson & Co., Ltd., Thornaby-on-Tees.

Fig. 137.—Jigging screen or screen conveyor.

mounted on springs, and reciprocated with a slow forward movement and a rapid backward one. By this means, the particles are continually jerked upward from the tray and gradually travel forward along the conveyor. If the tray is perforated or fitted with gauze, it acts as a combined conveyor and sieve (Fig. 137); as it may be made of great length, its screening efficiency is very high. They are usually 4-5 ft. wide, and are inclined at various angles up to about 18 degrees, according to the nature of the material. They are reciprocated at speeds up to 120 oscillations per minute, the stroke being usually about 5-9 in., about 2-3 h.p. being required. The arrangement of the supporting springs and reciprocating mechanism requires care and skill so as to avoid unnecessary vibration, and where two conveyors, one above the other, can

be coupled to the same reciprocating device, though with separate cranks, much greater durability is ensured.

Jig screens are not suitable for fine powders as they are too dusty, but they are excellent for separating sand from gravel. They are costly to instal and must, therefore, be used for large outputs.

Grids or grizzlies may be given reciprocating movement, either as a whole or by constructing them of loose bars and attaching alternate bars to an eccentric or crank which then gives them the requisite to and fro motion. (See also *Screen Conveyors*, p. 463.)

Reciprocating Feeder-screens are often useful for effecting a rough separation of coarse and finer materials prior to delivery to another machine. They may be used for a variety of purposes, of which only two need be mentioned.

(*a*) When a mixture of coarse and fine material is fed from a bin or crusher by a conveyor belt, the durability of the belt may be greatly increased by causing the fine material to reach the belt first and so form a cushion which protects it from the abrasive action of the larger pieces. This is effected very ingeniously and cheaply in an arrangement supplied by the Stephens-Adamson Manufacturing Co., of Aurora, Ill., U.S.A., which consists of a belt conveyor over which is mounted a hopper and a reciprocating grid or grizzly. The mixed material falls on to the grate and the finer particles pass through it to the belt, whilst the larger pieces pass along to the end of the grate and fall on to the cushion of finer material on the belt.

(*b*) When it is necessary to crush a material containing pieces of several different sizes, it is economical to screen it roughly so that the smaller pieces (which do not require crushing) do not enter the crusher. This arrangement sometimes permits a smaller crusher to be used, and it always results in a saving in power. One of the most effective screens for this purpose is a reciprocating grate which [illegible] acts as a feeder (Fig. 70). The mixed material falls [illegible] on to the reciprocating grate, the finer material which does not require crushing falling through into a chute which delivers it below the crushing rolls. The coarse material passes along the grate, falls into the crusher, and eventually joins that which has previously fallen through the grate.

Revolving Screens give the largest output of all so far as material larger than 20-mesh and less than 4-mesh is concerned. For finer materials, inclined vibrated screens, as already described, are preferable.

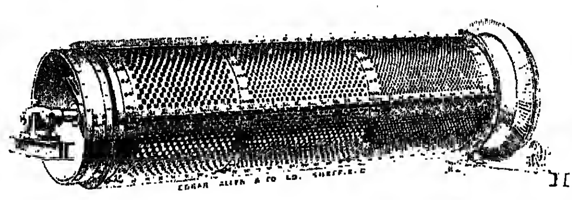
Revolving or rotary screens consist essentially of cylinders, polygons, or cones constructed of longitudinal bars on end-frames, perforated steel-plates, or metal gauze mounted on wooden or metal supports. The screens are rotated at a moderate speed. Those with longitudinal bars are specially suitable for very coarse screening, the bars being placed $\frac{1}{4}$-$\frac{1}{2}$ in. apart, and are particularly used for heavy work which would cause excessive wear on other rotary screens.

Rotary screens with perforated plates are used for separating pieces from $\frac{1}{8}$ to 4 in. diameter; they are not wholly satisfactory for pieces more than 2-$2\frac{1}{2}$ in. diameter.

Rotary screens fitted with gauze are suitable for separating the finest particles and all those up to $\frac{1}{2}$ in. diameter, though for holes more than $\frac{1}{8}$ in. diameter a perforated sheet is much stronger than wire gauze.

The unscreened sand is supplied to one end of the screen which is given a slight inclination, so that, as it rotates, the coarser material is carried through it whilst the finer particles pass through the perforations or the mesh.

The simplest form of revolving or rotating screen is a cylinder of perforated metal (Fig. 138) mounted on an internal shaft by means of ribs which form two or more "spiders." Nearly as simple, but having several important advantages, is a polygonal screen (Fig. 139) with five, six, or eight sides (usually six) constructed in a similar manner



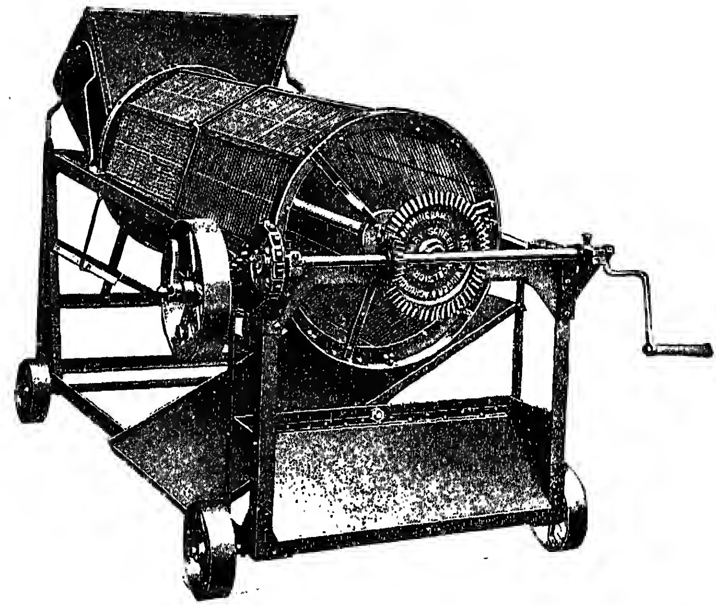
Edgar Allen & Co., Ltd., Sheffield.

FIG. 138.—Rotary screen.

to the cylindrical screen. The hexagonal screens are rather more expensive in first cost, but they have a slightly larger screening surface for the same "diameter," the shape increases the "tumbling effect" on the material and so increases the output to a small extent; repairs are made much more rapidly as well as more cheaply. If a cylindrical screen is broken, the repair (apart from a "patch") is extensive, but with a polygonal sieve it is merely necessary to remove one side and replace it by a new one; this is effected much more rapidly than the repair of a cylindrical sieve. This is a matter of great importance on a busy day, as the sieve need only be stopped for a few minutes in order to attach a new frame, whereas a cylindrical sieve must sometimes be stopped for several hours in order that one section may be taken off and replaced by a new one. When a cylindrical screen is made in sections which can quickly be replaced, the objection just mentioned is largely obviated and the advantage of the cylindrical form—which involves less wear and tear on the screen—is maintained. A cylindrical screen made in one piece may be cheaper in first cost, but after several years of rough usage it will be found to have cost more in

repairs and loss through stoppages than a screen of the same size made in suitable sections.

Instead of mounting the cylinder or polygon, as described, on a shaft running through the centre, it may be fitted with a hardened steel ring with a spur-wheel gearing and rotated on external rollers. This method is better in several respects, and enables the interior of the cylinder to be perfectly clear, thus giving more space as well as avoiding the wear and tear on the shaft. External driving of this type is used chiefly for the heaviest screens, the lighter ones



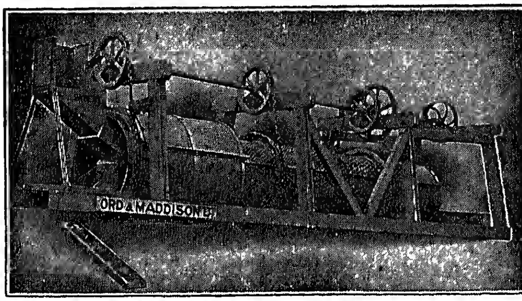
Parker, Winder & Achurch, Ltd., Birmingham.

FIG. 139.—Hexagonal screen.

being mounted on a central shaft, or (as in the rotary screens made by Ord & Maddison, Ltd., Fig. 140) suspended from several pulleys which, in revolving, turn the screen at the desired rate and ensure a very free and easy drive. A similar arrangement is employed in the screens supplied by W. A. Hiscox, Ltd., Derby. Screens which are not too large may be fitted with a disc or cap at one end; this constitutes the only mounting necessary. The cap is fitted to the end of a horizontal shaft which, in rotating, causes the screen to rotate at the same rate (see Fig. 141).

Conical Rotary Screens are similar to the ones just described, but are of a conical instead of a cylindrical shape (Fig. 141); the shaft being quite horizontal makes driving easier than is the case with inclined cylindrical screens having an intermediate shape.

The material is delivered through a chute to the small end of the screen and the tailings are discharged from the larger end. The greater perimeter of the larger end gives a more rapid rate of travel to the coarser pieces, thus freeing them more readily from the smaller ones and ensuring a somewhat better separation. The

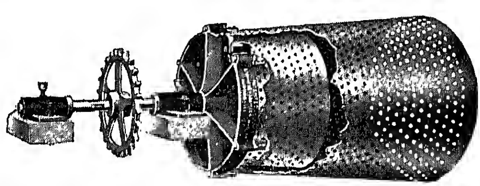


Ord & Maddison, Ltd., Darlington.

FIG. 140.—Suspended rotary screen.

conical shape of the screen and the fact that a horizontal shaft is used, also effect a saving in weight, reduce the amount of head-room, and greatly simplify the arrangement, especially if an elevator is used to feed the screens. In a cylindrical screen the elevator head must be mounted separately, but with a conical screen it can be mounted on the same shaft, thus simplifying the drive very considerably.

In some cases, in order to reduce the wear and tear caused by the fall of the material from the chute, a small screen is placed inside the larger one (Fig. 141), the material falling into this small



Stephens Adamson Co., Aurora, U.S.A.

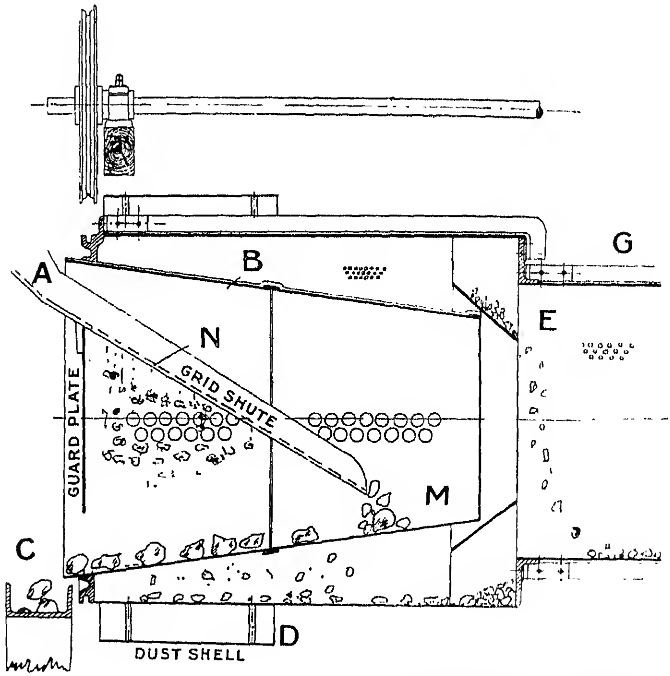
FIG. 141.—Gilbert conical screen.

receiver and then, at a much lower velocity, into the screen itself. In other cases several screens of different mesh can be arranged concentrically. In another type a number of conical screens are fitted on one shaft, the small end of one screen projecting into the large end of the next one. The material is fed in at the upper end of the first screen and is discharged progressively through the narrow end of one sieve into the large end of the next, and so on

through the series. An arrangement of this kind is sometimes used when washing and screening sand simultaneously (p. 400).

As shown in Fig. 141 a conical screen can be arranged with a free interior, *i.e.* the shaft need not go through the cone.

A very useful screen for separating sand and gravel is made by Ord & Maddison, Ltd., Darlington (Fig. 142), and consists of a cylindrical screen with a conical one inside it, the material being introduced into the cone at *M* by means of the chute *A*, which is



Ord & Maddison, Ltd., Darlington.

FIG. 142.—Concentric sand and gravel screen.

fitted with a grid *N* to take out the sand, which is instantly passed through the hole in cone *B* into the enlarged screen *D*, without mixing with the larger stones, thus ensuring perfect screening. All other stones are passed by gravitation towards the outer end *C*, the largest ones being delivered to an elevator or breaker as desired. The small stones and coarse sand after passing through the cone are raised by means of elevator wing-plates *E*, and may fall into a second cylindrical screen for further separation if required.

Tapering polygonal screens are also used, either singly or in series, those of hexagonal shape being generally preferred. They are preferable to conical screens for the same reasons that straight

hexagonal screens are preferable to cylindrical ones (see p. 457). Hexagonal screens are mounted in the same manner as conical ones, and are used for the same purposes.

Vibrating Revolving Screens.—When damp or adhesive sands are screened on a rotary screen, the latter may be vibrated by means similar to those employed for fixed screens. The most usual device is a loosely pivoted hammer-bar, so placed that it rests on a steel band surrounding the screen and fitted with four small projections or "anvils." As the screen revolves, the hammer-bar is lifted by the anvils and then falls on to the screen-band, causing the screen to vibrate. This arrangement is very noisy in action, but is fairly effective. Several similar bars may be used on the same screen if desired. The vibration is intensified if the screen is suspended from chains (Fig. 140) instead of being mounted on a central shaft.

Multiple Screens are those which can separate a mixed material successively into particles of several distinct grades or sizes. The simplest form is a long sloping sheet of metal composed of several sections each perforated with holes of a different size, but rotating screens can be arranged in the same manner and to great advantage. The section with the smallest sized holes is nearest the top of the screen and that with the largest holes is at the lower end, the intermediate sections being arranged progressively according to the sizes of the holes. Thus, if there are six sections, the material would be separated into seven grades, namely one for each section and the tailings which are passed over the end of the screen.

It is more usual to employ rotary screens (Fig. 138) than flat ones for multiple work on account of their larger output. It is even more important with multiple screens than with single ones that each section of the screen should be of sufficient length to effect a complete removal of all the particles it is intended should pass through it. A common mistake is to have the sections too short, with the result that the materials are imperfectly separated. The most generally satisfactory length of each section is 6 ft.

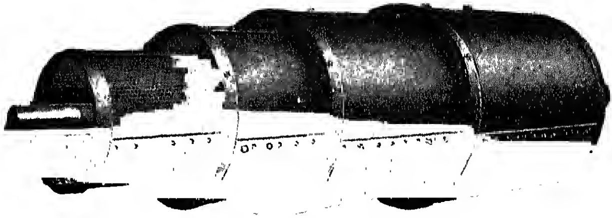
Various other forms of multiple screens are also in regular use. For instance, the screens may be quite separate, but so placed as to deliver their products to one another. This is the case when several conical screens are mounted on the same shaft (Fig. 103). Another and very important form of multiple screen is described in the next section.

Concentric Screens.—Instead of employing separate screens in series, it is often better to arrange them concentrically—inside one another (Fig. 143)—and to drive them by means of a common shaft. The coarsest screen is placed on the inside and the finest on the outside, the material being fed on the coarsest screen first. Fig. 144 shows a screen of this type in which the screen plates have been partly removed so as to show the facility with which they can be replaced when damaged. The advantages of concentric screens are :

(i.) Much of the wear and tear of the screens is confined to the coarsest one—which is the strongest—whereas in most other arrangements the wear is greatest on the finest screen, which is least able to withstand it.

(ii.) The arrangement is very compact and requires a minimum of space.

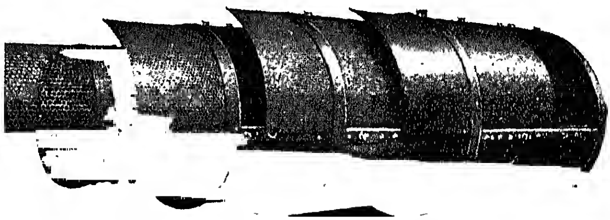
(iii.) The arrangement is very economical in power.



J. & F. Poole, Ltd., Hayle.

FIG. 143.—Concentric screens.

Another multiple screen which is very commonly used consists of an ordinary revolving cylinder with holes of the desired size, surrounded by one with smaller holes to act as a separator for dust and very small particles. Thus, if it is desired to separate ½-in. material and dust from coarse sand, the former is removed by the main cylinder and the latter is separated by the fine screen.



J. & F. Poole, Ltd., Hayle.

FIG. 144.—Concentric screen showing sliding screen plates.

Ratio of Apertures to Product.—It is not sufficiently realised that revolving screens must have larger holes than the particles they are intended to pass, because the inclination and the rotation of the screen both have the effect of making the effective size of the holes much smaller than their apparent size. For stones, the necessary ratio is readily found, but for sand it is much more difficult and, consequently, trials must usually be made of screens of various meshes. It is usually found that all the material passing through a 40-mesh rotary screen will also pass through a 50-mesh

standard sieve, and that the sand which passes through a 90-mesh rotary screen will pass almost completely through a 100-mesh standard sieve.

On account of the great difference between the true and effective sizes of the holes, it is important to check the sizes of the screened particles by hand screening with standard sieves from time to time.

Speed of Rotation.—The speed at which cylindrical rotary sieves are driven varies from 8-30 revs. per min., a speed of 16-20 revs. per min. being most usual. Polygonal screens may be driven at rather a lower speed than cylindrical ones, in some cases as low as 4 revs. per min. being sufficient for separating sand and gravel. This avoids much of the wear and tear which occurs in screens which are driven at higher speeds.

Dimensions of Screens.—The dimensions of rotary screens should depend on the extent of separation desired. Usually each section of the cylinder is 4-6 ft. long and 2-4 ft. in diameter. Ample length is essential to secure a clean separation, but it is by no means unusual—especially in screens containing several sections in series—to find each section is much too short to do its work properly. This can best be ascertained by carefully examining the respective screened products after passing them through standard hand-sieves.

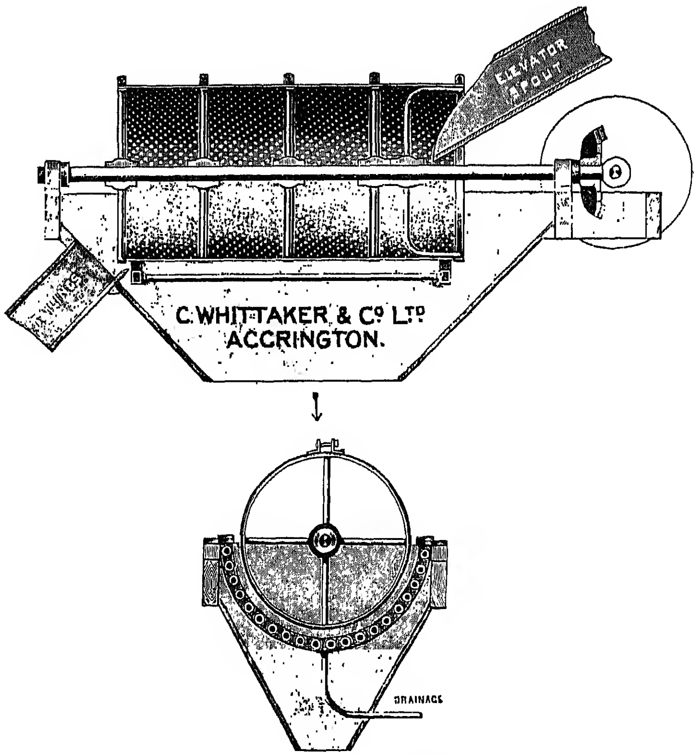
Heated Screens.—When the sand is damp it will not pass readily through or along a screen. This difficulty may be largely avoided by fitting a number of steam-pipes beneath the screen so as to partially dry the sand and thus facilitate its passage through the meshes. Fig. 145 shows an arrangement of this type attached to a rotary sieve. If the sand is very damp, however, it will be cheaper to use a rotary or other dryer prior to screening.

Screen-conveyors.—It is often convenient to combine a screen and conveyor in such a manner that a material is screened during transport. Most screens do this to some extent, but the term "screen-conveyor" or "conveyor-screen" is usually confined to those appliances which are primarily conveyors, but also act as screens. Such appliances are of several forms, and considerable ingenuity is often exercised in adapting fresh combinations of screens and conveyors to a particular purpose.

One type of rotary screen-conveyor (Fig. 73) consists of a stout shaft, on which are mounted a number of circular plates or discs set at a prearranged distance apart. This shaft is fitted in a broad slot, in an ordinary chute, so that when the material falls upon the edge of the disc the smaller pieces pass between them and so fall out of the chute, whilst the coarser material is carried round the circumference of the revolving plates and into the lower portion of the chute. This appliance is chiefly of use as a feeder for crushing-plants, as it takes up very little space horizontally.

Another type of screen-conveyor consists of an endless belt (Fig. 71) composed of links a suitable distance apart and driven by a pair of sprocket pulleys. Between the upper and lower

parts of the belt should be a hopper to receive the small material passing between the links and convey it to a suitable bin. The coarser material is carried to the end of the belt and is then discharged. As the belt can be of any convenient length, a very effective separation is made with the minimum amount of head-room. This arrangement also has the advantage of being self-cleaning as the links pass over the sprockets, whereas the spaces



C. Whittaker & Co., Ltd., Accrington.

FIG. 145.—Steam-heated screen.

between the bars in an ordinary grate or grizzly are liable to choke. Below the belt a brush should be fitted to remove any adherent particles, so as to prevent them being ground by and damaging the return pulleys. A screen-conveyor of this type, with a total length of 6 ft., will have an actual screening surface of about 3 ft. 6 in.

Another equally important type of screen-conveyor consists of an ordinary jigger conveyor, the pan of which is perforated so that it also acts as a sieve (see p. 455), the smaller particles falling

through the perforations, whilst the larger ones are "jigged" along the conveyor by a sharp to-and-fro motion imparted to the appliance. Such a jigger sieve has the great advantage of moving the material uniformly over the surface, and, being horizontal, it removes a large percentage of fine material, thus giving cleaner tailings than a sloping screen. At the same time it has the advantage over ordinary horizontal sieves of lifting the coarse material from the screen at each movement, instead of at longer intervals, as in an ordinary to-and-fro sieve, and, as the tailings are automatically discharged, there is no stoppage of the sieve to remove "rappings." The manner in which the sieve is moved ensures a greater "life" than in the ordinary to-and-fro sieve, and the screening surface is much greater than the latter in proportion to the power required. As the top of the trough is open, the material can be inspected at any time, and any damaged or defective part of the conveyor can easily be seen and repaired.

Dust-proof Casings.—Where sieves are likely to produce much dust, as in fine screening, it is desirable to enclose them in a dust-proof casing, which prevents a serious loss of material and avoids injuring the health of the workers. The shape of the casing depends on that of the screen; it may usually be of wood or sheet-iron plates, and should be fitted with doors to give ready access to the interior. In some cases a fan is used to draw the dust into a dust-collector, from which it may be recovered without loss, whilst the air is allowed to escape. These collectors are of two types—(*a*) *filters* in which the dust-laden air is passed through cloths or into bags or "candles" which retain the dust, but not the air; and (*b*) *separators* in which the speed of the air is reduced to such an extent that it cannot carry the dust any further, but is obliged to deposit it. Filters are usually the more efficient when in good order, but require frequent attention. The best results are obtained by passing the air first through a separator or depositing chamber, and then through a filter.

CLASSIFYING

The term "classification" is particularly applied to the separation of a material into groups, the particles in each group having the same rate of falling from suspension in water. It may serve either of two purposes: (*a*) separation of particles similar in size, but of different specific gravity, and (*b*) separation of particles of uniform specific gravity, but of different sizes. The first purpose has been described in Chapter IX.; the second purpose is that known as "grading," and is mentioned here because classification by means of water or air may often be conveniently employed for grading some very fine materials which cannot conveniently be separated by sifting. Various methods of classification are largely used for separating metalliferous sands into a portion rich in the

desired metal and a second portion or gangue free from metal; the same methods are also used for grading finely ground or levigated silica in order to separate the finer from the coarser particles.

When a classifying device is used for separating fine particles from coarser ones, all the particles must be of approximately the same specific gravity, as, otherwise, large particles of low specific gravity and small particles of high specific gravity will both be collected in the "coarse" portion.

The factors governing the speed of settling are given on p. 250.

The apparatus used for water-classifying is practically the same as for washing (p. 384) or concentrating (p. 413), whichever may be more suitable. The chief forms of classifier are: (*a*) troughs such as those used for washing (p. 385) and concentrating (p. 415); (*b*) pyramidal or conical separators such as the spitzkasten (p. 398), spitzlutte (p. 398), or separating cones (p. 394); (*c*) jigs such as are used for concentrating (p. 420); and (*d*) centrifugal machines (p. 407).

Classifying with Air

Air separators are very valuable for classifying fine particles of dry material which are too fine to be dealt with by screening. They are based on the principle that if the mixed particles are suspended in a current of air of regulated speed, this stream of air will carry the finer particles of sand, etc., along with it, whilst the heavier ones sink, and may be removed through an opening in the bottom of the machine.

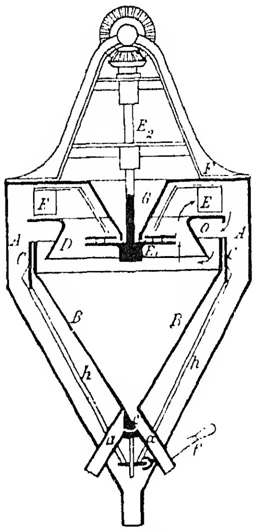


Fig. 146.—Section of air separator.

The suspension is sometimes effected by blowing a current of air into the material to be treated, but a far more effective suspension is obtained by allowing the particles to fall on to a rapidly rotating disc. The centrifugal force imparted by the disc to the particles causes them to fly off the disc at varying rates according to their respective sizes, and so effects a preliminary separation, whilst the current of air which receives them after they leave the disc completes the classification.

The air separators of this type (Fig. 146) now generally used were invented by Mumford and Moodie, but they are manufactured by several firms, as the chief patents have long since expired.

The material to be sifted is introduced into the separator through a hopper G in the centre of the top-plate F, and falls on to a rotary spreader E_1, which throws it outwards by centrifugal force

in a thin stream into the current of air drawn upward through the apparatus by means of a fan *E*, *E*. The fine particles are carried upwards and pass into the outer casing *A*, which leads to a chute, whilst the coarser particles, which are not lifted by the current of air, fall into the inner casing *B* and are collected by means of a second chute having two outlets *a*, *a*.

In an improved form of separator known as the Selektor, a number of metal rings are arranged beneath the spreading plate, and the air is made to travel up the casing until it meets the descending stream of material and then between the metal rings, so that the fine material is drawn through these into the inner casing, whilst the coarser particles fall straight down into the outer one. This apparatus gives a somewhat sharper separation than the simpler type first mentioned.

The speed of the air passing through the apparatus can be varied within wide limits in order that particles of any desired size may be separated, and, if necessary, several separators can be used in series so as to obtain products of various distinct grades.

The air discharged from the separator may contain a considerable proportion of very fine dust, which should not be passed into the atmosphere, but should be collected by means of one or more large conical settling tanks, or "cyclone separators," arranged in series, the last traces of dust being held back by means of a suitable filter. If the fine dust is quite useless a scrubbing tower with sprays of water may be more convenient than a filter.

By using cyclone separators of different diameters, the powder may be separated into an equal number of grades of different fineness.

To obtain the best results, the material supplied to an air separator should not contain any notable proportion of particles larger than $\frac{1}{8}$ in. diameter; and the nearer the material approaches the nature of a powder, the better will be the separation.

Air separators are only satisfactory when properly supplied with suitable material, but are then rapid in action and have a large output. It is most important, however, that the material should be sufficiently dry, or the particles will adhere together and will not be properly separated by the current of air. To assist in the separation of damp materials the use of hot air is sometimes recommended, but it involves difficulties due to its feeble carrying power. The machine must be fed at a constant rate, and special care is needed not to overload it, so that a mechanical feeding device is desirable.

It is often convenient, and quite satisfactory, to connect an air separator to a ball mill, the product from the mill passing into the separator, and the "tailings" being returned to the mill for further grinding. The simplest means of delivery from the mill to the separator is a bucket elevator, but if the whole of the product is sufficiently fine it may be drawn from the mill by a current of air moved by the fan in the separator.

Air separators have the advantage over sieves of being very rapid in operation, having a large output, and being capable of grading particles which are too small to be separated by sieves. They require little power, and only occupy a small floor space.

The fact must not be overlooked that an air separator tends to separate the particles in accordance with both their specific gravity and size, as a minute particle of high specific gravity would be carried away by a stream of air of the same speed as would carry a large particle of smaller specific gravity. In the case of comparatively pure sands, where all the particles are of the same specific gravity, the separation is strictly according to size, but this would not be the case with a powder composed of substances of widely different specific gravities.

ARRANGEMENT OF PLANT

The various parts of the plant used in crushing and purifying sand should be so placed that the sand or rock travels by gravity through the crushers and screens, washers, etc., to the trucks or to the storage bins, even if this necessitates raising the raw material in lifts or elevators to the crushers, etc.

The discharge outlets of the bins should be, as far as possible, at a convenient height above the railway, though each works must be considered separately and local conditions taken fully into consideration. It is not unusual to have the final products much below the railway, so that they have to be raised to the latter ; when this is the case it will usually be found, on investigation, that a cheaper arrangement would have been to have used smaller wagons or a conveyor to raise the sand or rock to a height sufficient to deliver the finished product above the top of the railway trucks. A typical arrangement of a plant is shown in Fig. 121 (p. 424), but conditions differ so greatly in different works that "standard designs" are of little value. The skill of the expert is largely shown by an efficient and economical arrangement of the plant to suit local conditions.

CHAPTER XI

STORAGE, PACKING, AND DESPATCHING SANDS

The problem of storing, packing, and delivering sands or crushed rocks is one which needs careful consideration in arranging the plant, as its output is largely controlled by the storage capacity, and a " bottle neck " may mean a serious loss in working. During the winter months the preparation of sands is generally discontinued, but as there is usually a limited demand for material during these months, suitable arrangements should be made to provide sufficient storage capacity to meet the demand. It is most important that this market should not be neglected, as high prices can often be obtained during the winter months on account of the greater scarcity of available sand.

Manufacturers of crushed stone can usually work all the year round, but as the demand is not nearly so great during the winter as in the summer, they must either work the plant at less than its full capacity, or provide storage space for all the material in excess of demands.

Two methods are available for storing sands, etc.: (i.) storage in bins, and (ii.) storage in open piles.

It will be obvious that the cost of bins for storing material for four months or more would be exorbitant, so that large quantities are usually stored on the ground in piles or "dumps." The situation of these dumps should be carefully considered, as it should fulfil the following conditions: (*a*) It must be sufficiently near to the plant so that dumping can be carried out economically. (*b*) It must not interfere with any other part of the works, and must not render any useful material inaccessible. (*c*) It must be conveniently placed so that the sand can be readily loaded into trucks for transport by rail, road, water, or whatever means are employed. (*d*) There must be no danger of damage if any slipping of the material in the piles occurs. (*e*) If the sand is likely to remain in the pile for some time it may require further treatment, such as screening before it is loaded for transport, in which case it must be easily transported to the machine used for such treatment.

Ground storage, when arranged in accordance with the above-mentioned rules and any other local conditions which may arise,

is very cheap, and amply repays the cost of storage. On the other hand, piles which are badly placed may prove to be important sources of loss. The delivering of the material to the piles is preferably made by means of a belt conveyor or ropeway (Figs. 147 and 148), arranged so as to pass over the pile and discharge on to

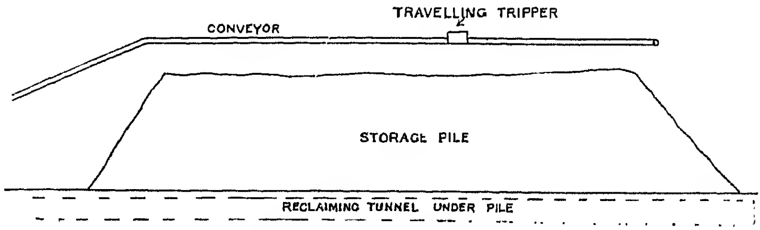


FIG. 147.—Open pile storage.

it. This is by far the cheapest method, provided care is taken in its installation. A canvas belt is quite satisfactory for sand, but rubber is better for crushed stone. The details of construction to be noticed in connection with belt conveyors are described on pp. 328-335. The conveyor receives the material direct from the screens or other parts of the plant, and should be arranged so as to give ample tipping space. The conveyor may be discharged by any suitable automatic arrangement, such as by scraping or

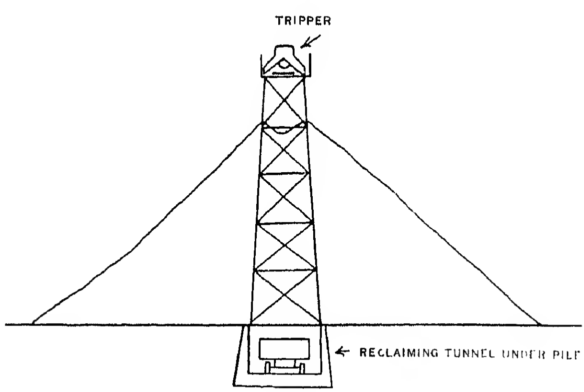


FIG. 148.—Open pile storage.

tilting the belt (Fig. 55). The latter is better, as it does not abrade the surface of the belt so seriously as a scraper. The serious effect of a scraper is due to its being stationary whilst in use; the damage is greatly lessened if the lower part of the scraper consists of a brass roller, mounted on ball-bearings and running the length of the scraper. The friction between the belt and roller causes

the latter to revolve and so reduces the scraping effect to a minimum.

The chief difficulty experienced in constructing temporary piles of sand or similar materials is due to the fact that an over-

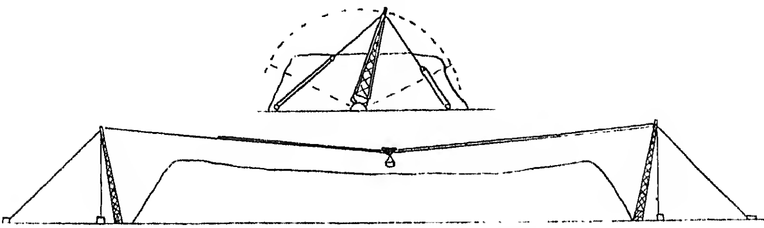


FIG. 149.—Harrington rocking cableway.

head conveyor or ropeway forms a long narrow pile instead of a short broad one. This is an almost inevitable result of the use of such appliances. It may be obviated to some extent by having the belt or rope supported on uprights which are pivoted near their base, so that their tops may be moved through a considerable angle to either side of the vertical position (Fig. 149). By this means the centre of the pile may be extended horizontally on either side of the vertical supports to a distance equal to the maximum height of the pile. Thus, if the pile is 30 ft. high, it can by this means be extended so as to consist of three separate long piles parallel to each other and having their centres 30 ft. apart. If the angle of repose is taken as 40°, the total width of the three piles will be 131 ft., and as the space between them can be filled up level with the top of each pile the total amount of material present will be about $2\frac{3}{4}$ times as much as if a single pile had been formed by the same conveyor with fixed vertical uprights. The only difficulty with this arrangement is the provision of a structure to which to attach the horizontal guy-ropes which are needed when the supports are in a steeply inclined position.

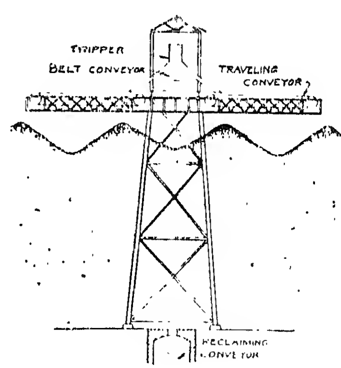


FIG. 150.—Transverse conveyor.

An alternative method is to provide a movable transverse belt below the main conveyor (Fig. 150), and to use this to extend the width of the pile.

It is sometimes desirable to have retaining walls on either side of the tip so as to prevent the material spreading too far.

Storage in open piles is more common in this country than any other method, but it is not really economical if the piled material has later to be loaded by hand into wagons. It is far better to store as much as possible of the material in bins, so as to avoid the cost of rehandling. In addition, the bins keep it clean; this is especially important in the case of purer sands such as those used for glass-making. In America, bins are used far more than in this country.

Reloading.—Various methods are used for reloading the sand or crushed stone. The use of labourers with shovels is the most common, but if there is a large amount of material in the pile it will usually be cheaper to employ a mechanical loading device. One of the simplest of these consists in running a bucket loader, such as is described on p. 308, up to the pile and loading direct into trucks; or if the rail does not run sufficiently near to the tip, the bucket loader may discharge on to a belt conveyor which conveys the material to the trucks, or to the plant for recrushing or screening.

Grabs, or any other suitable methods of loading (see Chapter VII.), may also be used, different conditions necessitating different methods of working.

Another useful method of reloading consists in having a trench covered with stout planks beneath the tip. Wagons may be run along the trench and filled from the pile above as in the case of a simple hopper. The disadvantage of such an arrangement is that the cost of trenching is often as great as the construction of a bin of sufficient size. The top of the trench should be sufficiently strong to support the great weight of material piled above it. Such a trench may be built of any convenient size, though if railway trucks are to be used it should be at least 15 ft. wide and about 15 ft. high. It is often convenient to arrange the rails so as to have a slight slope, which aids in passing the trucks through the tunnel, or some mechanical haulage device may be provided. If desired, a belt conveyor may be run through the tunnel instead of cars. In such cases, the trench need only be about 7 ft. square. A further disadvantage of such a trench or tunnel is that the whole of the material cannot be loaded through it, as the lower portion of the pile will not slide into the trench. Other means must, therefore, be employed for recovering that portion of the pile, or it may be left so as to provide permanent slopes down which the upper part of the freshly tipped sand may slide into the tunnel.

Storage bins of wood, brickwork, or concrete are used for holding a comparatively small amount of material. In most cases, the capacity of the bins is only about two or three days' supply on account of the great expense involved in their construction; the remainder of the stock on hand is usually stored in open piles as described previously.

Storage bins usually consist of square, rectangular, or round bins, supported on columns, or by other suitable means, and having

a conical or inverted pyramidal hopper at the bottom down which the material passes to an outlet in the base. Other outlets in the sides of the bins are convenient for loading carts. The outlets should be closed by suitable "gates" or slides, which should be easily operated and yet should be quite tight when closed. Some "gates" are difficult to use satisfactorily because they have been designed for gravel, or other coarse material, and not for sand. A slide with rackwork and pinion, if kept properly lubricated, is usually the most satisfactory "gate" for sand bins. The bins may be of any convenient height, though an excessive height will unduly increase the cost of construction, as the bins must be designed to withstand the pressure of the sand in them. A bin 16 ft. square and 48 ft. high from the bottom of the hopper to the top of the bin will hold nearly 400 tons of sand, assuming that the sand weighs approximately 90 lb. per cu. ft. This is about the maximum convenient size of bins, especially when the cost of construction is taken into consideration. Much shallower bins are often used, another very convenient size being about 18 ft. square and 30 ft. high; such bins have a capacity of nearly 270 tons.

The sides of the hopper should slope at an angle of about 60 degrees with the horizontal so that the sand will readily slide down the sides. Too small a slope will cause clogging of the sand in the hopper, and trouble is then certain to result.

Ample space should be left beneath the hopper so that full-sized railway trucks may be run underneath, the rails beneath the bins forming a siding from which the trucks can be run on to the main line.

The bins should preferably be covered over with a permanent roof so as to protect the material from the weather. In some cases, the whole of the plant is erected over the bins, and so serves as a roof.

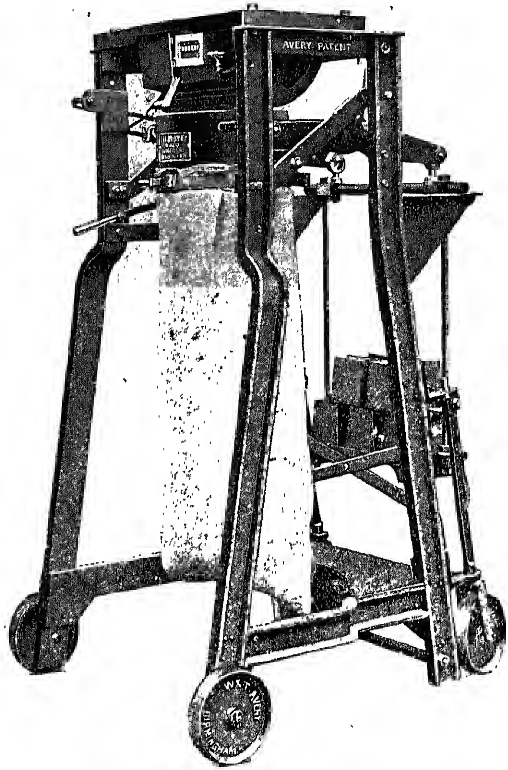
The details of design and construction of the bins are preferably left to a firm skilled in such work, as an accident resulting from defects due to amateur work might be disastrous.

The material is conveyed to the bins by different means according to the respective locations of the bins and machinery. When the bins are below the machinery, the material may be carried from the latter by means of chutes; whilst if the machinery is below the level of the top of the bins, the sand must be raised by means of elevators and afterwards discharged into the bins. Where several bins are to be filled with the same material it may be distributed by means of screw or belt conveyors. Grabs (p. 287) are also used for filling the bins and, if necessary, for lifting material from the bins and loading into wagons. In this way a bin can be emptied from the bottom and top at the same time.

Bagging or Sacking.—The purest sands, such as those used for glass manufacture, are sometimes packed in sacks for transport. The sacks may be filled either by hand or by an automatic machine.

The former is preferable for small quantities, but where much material is put into sacks or bags a machine is best.

Automatic sack-fillers (Fig. 151) usually consist of a balance to one arm of which is attached the end of a tube through which the sand passes from the bin or hopper, weights being attached to the other arm. The sack is fastened to the end of the discharge



W. & T. Avery, Ltd., Birmingham.

FIG. 151.—Sack-filler.

tube and is filled by opening a valve in the tube from the bin. When the weights and the sack balance each other, the valve is automatically closed and the sack removed and tied. In some forms of bagging machine, the discharge tube is in the form of an inverted Y and with balances; one sack is filled by the sand passing down one branch of the Y, and the other is filled by reversing the feed valve. In this way, the sacks can be filled more quickly than with a plain feeding tube.

Despatching.—Sand may be delivered to the customer by various means: for short distances motor lorries (p. 340) are probably the best; for longer distances railways (p. 342) or water carriage (p. 342) is necessary.

The lorries, trucks, barges, etc., which may be used for conveying loose sand should be cleaned carefully before being filled with the material, and should preferably be kept for conveying sand and nothing else; otherwise the sand is liable to be contaminated by foreign matter, with results which may, in some cases, be serious. Where the sand is carried in bags, this precaution is not so important, though even then clean trucks, etc., are preferable to dirty ones.

For most purposes, the sand may be despatched in ordinary open trucks, wagons, or barges, as it is not affected by weather, but covered conveyances should be used for specially pure sands, such as those used for glass manufacture, etc.

END OF VOL. I